STAND-PIPE ACCIDENTS AND FAILURES

IN THE UNITED STATES.

A CHRONOLOGICAL RECORD OF ACCIDENTS TO AND FAILURES OF WATER-WORKS STAND-PIPES IN THE UNITED STATES, WITH FULL DISCUSSIONS AND ASSIGNMENT OF THEORIES.

ALSO A DISCUSSION OF CURRENT PRACTICE IN SPECIFICATIONS FOR STAND-PIPES AND OF OTHER RELATED MATTERS.

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WITH 37 ILLUSTRATIONS, NUMEROUS TABLES, AND AN INDEX.

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PREFACE.

It is only within very recent years that the water-works stand-pipe has forced for itself recognition as a powerful destructive agency. The growing frequency of accidents to water-works stand-pipes has indicated the need of a reform in their design, construction and use. The substantial improvement which has been effected in steam boilers through the systematic investigation and analysis of boiler explosions, has suggested the possible value of a similar inquiry into the failures of stand-pipes. The record here presented is the direct outgrowth of this suggestion.

As originally contemplated, the record was to consist simply of a compilation of facts and data relating to the various cases described, but it early became evident that the investigation would lack a very important feature should no attempt be made to digest the compiled facts for the purpose of formulating a definite theory for each accident or failure included in the record. An effort has therefore been made to meet this requirement by giving close consideration to all available information bearing upon the conditions and circumstances attending or leading up to the several accidents. The claim is made for the adopted theories that they are not merely plausible, but that they are probably more nearly in line with the recorded data than any others which may be assigned. It was for obvious reasons quite difficult to use the desired freedom in some cases, without running a risk of injuring innocent parties, or, perhaps, recording strictures of too great severity. There are doubtless those who will be disposed to take exception to some of the theories advanced in the following pages. It was with the view to afford to such an opportunity for independent investigation of the cases questioned that the list of references to sources of information was given at the conclusion of each description. It is but fair to

state that a broader scope assumed for the investigation, almost from its inception, has served to stimulate a spirit of persistence both in the compilation of full statements of fact, and in the equally important matter of excluding, or at least qualifying, information of doubtful character.

With the exception of a few additions and revisions, the original record comprising the body of this book is a reprint of a series of articles which appeared first in Engineering News during the months of April, May and June, 1894. Certain accidents of a more or less obscure character were overlooked in the preparation of the original record. These cases and a few accidents which have taken place during the intervening twelve months were presented in serial form in Engineering News of April 25 and May 2, 1895. This supplementary record forms Appendix I.

Appendix II., which contains an analysis of the phenomena immediately following the initial rupture of the Peoria stand-pipe, is inserted by the publishers as the book goes to press, with the consent of the author. The matter thus presented is a communication from Mr. D. H. Maury, Jr., Superintendent of the Peoria Water Co., previously withheld for the reasons stated in the publishers' note introducing the Appendix. The chief value of the Appendix is in the plan of the ruins and development of the demolished lower portion, the comments themselves being essentially the same as those presented jointly by Mr. Maury and Mr. C. B. Davis in their report of the failure, which appeared in Engineering News of April 5, 1894. Furthermore, the analysis given in this Appendix does not seem to be discordant with the more elaborate report by Mr. J. A. Harman, which is quoted in full in the description of the Peoria failure, in the body of this book, from Engineering News of April 26, 1894, and the summarized statement by Mr. W. C. Parmley, Assistant City Engineer, likewise quoted from

Engineering News of May 10, 1894. In view of Mr. Maury's intimate knowledge of the details of the wrecked stand-pipe, acquired from close and deliberate personal investigation, there is much cause for regret that he has not seen fit to discuss the cause of the accident.

Previous to the publication of the original record in serial form, the need of a parallel investigation along the line of current practice in stand-pipe specifications and their enforcement became evident. An inquiry of this kind was undertaken, the result appearing first in the form of a contribution to Engineering News of Feb. 28, 1895, and now as Appendix III. of this book. This discussion drew forth two valuable communications on stand-pipe construction and improved shop methods by Messrs. Freeman C. Coffin and Wm. R. Webster, respectively. These contributions appeared in Engineering News of May 2, 1895, and because of their permanent interest and value are made a part of this book as Appendix IV. The assignment of this liberal space to the discussion of a matter which was not contemplated in the work as first undertaken, is based upon the belief that reform in this field of construction may be accomplished most efficiently, and perhaps solely, through the associated study of "cause" and "prevention."

Besides the communications just mentioned, Appendix IV. contains one from the Stanwix Engineering Co., in relation to the specifications for the stand-pipe at Schenectady, N. Y., designed by them. The Appendix is concluded by an abstract of an article on the construction of the stand-pipe at St. Bernard, O., by Mr. Geo. Hornung, the designer of the structure, which appeared in Engineering News of May 23, 1895. This description is given space because of its value in connection with recent developments in the methods of erecting stand-pipes, the use of power riveting being of special significance.

In discussing the enforcement of specifications in Appendix III., much stress is placed upon the importance of preserving in permanent form proof of the scope and character of the structural tests of material used in the stand-pipe. An emergency requiring the production of such evidence is not apt to occur with very many stand-pipes, and for this reason the necessary precautions are often overlooked. It is well to know, however, that proof of quality may be demanded in cases where no accident of any kind has been sustained. An instance of this kind was recently brought to light by litigation based on alleged depreciation of real estate values contiguous to a stand-pipe, the suit having been suggested by the failure of a stand-pipe in a neighboring city. In such a suit, the evidence of most weight obviously should be the testimony of the designing and constructing engineer, supported by authentic certificates of structural tests made by disinterested experts. In the particular case referred to, however, such evidence would have been weakened by the fact that the engineer of the structure causing the litigation had also designed the stand-pipe whose failure had suggested the damage suit.

The author desires here to acknowledge his indebtedness to the large number of engineers and others who have contributed generously to the stock of information contained in the following pages. Special credit is given throughout the book whereever the circumstances of the case have made this proper. The warm interest in the subject of this monograph, which has been displayed by those consulted in the progress of the investigation, warrants the hope that the reproduction of this record in permanent form will be regarded with favor by those engaged in stand-pipe design and construction, particularly since no attempt to publish a complete record of the kind has hitherto been made.

Champaign, Ill., June, 1895. W. D. P.

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STAND-PIPE ACCIDENTS AND FAILURES.

Introductory.

In view of the extensive use within recent years of the elevated tank, commonly known as the stand-pipe, in connection with water supplies, there is no reason for surprise in the fact that a number of such structures have failed entirely and that others have sustained more or less damage from various causes. The records of this class of accidents heretofore published have been very incomplete either as to the number of cases described or in the extent and nature of the information given. The record which is here presented is the result of an extended investigation of the subject and it is believed to be more complete than any heretofore compiled. While it is quite possible that a few instances of slight damage may not be included in the list, an extended search indicates that no accident of importance has been omitted.

At first thought, it may appear improper to include in such a record instances in which the resulting damage was relatively very slight, but the inclusion of several such cases seems fully warranted by the fact that a careful consideration of them serves to throw much light upon the causes and conditions which have led to other and more serious accidents.

Such a record should include a statement, not only of the conditions existing at the time of the accident, but also of the principal details of the structure itself. In attempting to comply with these requirements, photographic views have been secured in a number of cases, of which several half-tone reproductions will be presented.

The investigation would also lack a very essential feature if the question of cause of accident were not especially considered. To this end comments of a more or less critical nature have been made and, in order to avoid the embarrassment which might result from such freedom, personal references of a damaging nature have been studiously omitted.

The term "stand-pipe," which is ordinarily restricted to relatively tall structures, is here used in the broader sense to include all of the forms of water-works tanks coming within the range of this record.

While the several descriptions are, in themselves, of interest historically, it should be observed that the most valuable and instructive points in connection with the subject are developed in the classification. The latter is believed to be the most extensive and, perhaps, the only one of the kind yet made. The classification above mentioned comprises a summary of the more striking facts developed in the detailed description and is accompanied by a brief discussion. Although the facts have, to a great extent, been compiled through reference to the files of technical periodicals, many of the more important points have been communicated to the writer and have not heretofore been published. Much of importance has been obtained only through persistent research and, in several instances, obscure sources of information have been reached by chance. The list of special references accompanying each description includes all sources from which facts have been drawn. The writer desires to here acknowledge the uniform courtesy and attention which his inquiries have received.

After the body of the following record and the accompanying discussion had been put in type, information was obtained from various sources relative to a number of omitted cases. Owing to the

difficulties attending an extensive revision of the original discussion, it was deemed best to present the above-mentioned cases in the form of an appendix, a plan which has proven peculiarly favorable to the insertion and revision of descriptive matter up to the time of going to press. The supplementary record, with a brief discussion of the omitted cases, will be found in Appendix I.

The intimate relation between a record of accidents and the question of prevention has led to a request that something along the latter line be given. This request had been partly anticipated and provided for in the preparation of the general discussion already referred to, but the character of that discussion is such as to forbid going into details upon many points. For this reason it has been thought best to present in a separate place some points which, although closely related to the record of failures, do not properly come within its scope. In Appendix III. is collected matter related mainly to the questions of quality and tests of plate metal, and it is hoped that the points there presented may not be wholly without value to those engaged in the preparation of stand-pipe specifications.

Cleveland, O., 1868.

The earliest stand-pipe failure* of which a record is available occurred at Cleveland, O., early in 1868. The only mention of this accident to be found is the following brief account given by the late J. D. Crehore:

> Sometime in the spring of 1868, in Cleveland, O., a new wrought iron tank 60 ft. in diameter and filled with water to the height of 18 ft., burst and fell asunder. The thickness of the single-riveted sheets composing this tank did not exceed 3-16 in.

Diligent inquiry has failed to develop anything

* Although the Cleveland accident was the earliest "total failure" of which mention could be found, it is proper to call attention here to the fact that an earlier incident, the leaning of a brick water tower during its construction in 1854, at Chicago, Ill., is recorded in Appendix I.

definite except that the tank in question did not belong to the water-works system of the city of Cleveland. A suggestion that it was a new oil tank being tested by water pressure seems plausible, but no facts either confirming or disproving this supposition could be secured.

Under the conditions above stated the unit stress upon the 3-16-in. plate, assuming 50% efficiency in the single riveted joints, would have been about 30,000 lbs. per sq. in. This fact in itself fully explains the accident, although other conditions, such as defects in individual plates, may have had some bearing in hastening the destruction of the tank.

References.—Van Nostrands' "Engineering Magazine," Vol. XXV., p. 330 (October, 1881). Correspondence with the Water Department and with the Standard Oil Co. (1893). Correspondence with W. W. Crehore, C. E. (1893).

Jersey City, N. J., Dec. 31, 1869.

On Dec. 31, 1869, the stand-pipe at Jersey City, N. J., collapsed and fell. It had been constructed in 1859 of plate iron ½ to 7-16 in. thick, and consisted of two parts, the lower portion being 160 ft. in height and having a diameter of 6 ft. at the bottom and of 4 ft. at its top. Resting upon, and braced to, the lower section by angle irons was a small cylindrical tank 10 × 10 ft., making the entire height 170 ft. It is said to have been riveted together in a horizontal position and afterward hoisted into place, which fact, it will be seen, probably weakened the structure.

The following statement by the engineer in charge of the pumping engine at the time of the accident has been secured through the courtesy of Mr. W. W. Ruggles, Chief Engineer of the Jersey City Water Department:

The weather for a week previous to its fall had been about zero in the warmest part of the day, and for three days before its fall the temperature ranged from 2 to 10° below. The stand-pipe was nearly choked with ice. The engineer turned a steam pipe 2 ins. in diameter into the stand-pipe just above the discharge

pipe, and tried in that manner to dislodge the ice. It relieved it partially and would probably have remedied the matter entirely, but for what followed. The tank, 10 ft. in diameter, which rested on top of the pipe, 4 ft. in diameter, was loaded with ice 3½ ft. thick. The ice in the stand-pipe was from 2 to 3 ins. thick, and the weather bitter cold. The wind, which had been in the northwest, suddenly turned to the southwest, and grew very warm. The sun and the wind together melted the ice on the south side of the pipe somewhat, and it toppled and fell. The pipe buckled at the point where, at the time it was hoisted into position, the lashings had been put about it.*

In falling, the stand-pipe broke into three pieces. A statement which has been made to the effect that it was "repaired and re-erected," is incorrect; for a new stand-pipe, having a height of 160 ft. and diameters of 6 ft. 6 ins. and 4 ft. at base and top, respectively, was built on the site of the former one. In 1872, a brown-stone and brick tower, 210 ft. high, was built, inclosing with the above stand-pipe, a second one erected in 1871. The latter, situated 15 ft. from the other stand-pipe, is also 160 ft. high, but it has a uniform diameter of 6 ft. Both of them received a coating of silicious composition to prevent oxidation.

References.—Engineering News, Vol. VIII., p. 226 (June 4, 1881). "Proceedings of American Water-Works Association," 1888, p. 106. "Engineering and Building Record," Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). "Manual of American Water-Works," 1889-'90, p. 203. Correspondence with Chief Engineer, Jersey City Water Department (1893).

Sandusky, O., Oct. 20, 1878.

This stand-pipe, built in 1876-7, is of steel and consists of two concentric shells, the outer, 25 × 180 ft., and the inner high-pressure pipe, 3 × 229 ft. The thickness of the outer shell ranges from ⅞

* Since the above description of the Jersey City failure was prepared, information has been received from Mr. D. C. Cregier, of Chicago, to the effect that at the time of this accident its cause was assigned by some to the fall of the ice, and that the conical form of the structure was believed by some engineers to have had an important bearing, because of the greater tendency of ice to fall with the diameter of the stand-pipe increasing downward.

to 3-16 in., the bottom course being leaded into a segmental cast iron shoe which is set in a groove cut into the rock. The anchorage consists of twelve 1½-in. iron rods riveted to the second course of plates and wedged and leaded 3 ft. deep into bed-rock.

The high-pressure pipe originally had a thickness of ¼ in. for the first 100 ft., 3-16 in. for the second 100 ft. and ⅛ in. for the remaining 29 ft. An accident which occurred to this inner stand-pipe is thus described in the Annual Report of the Sandusky Water Department for 1878:

> During a fire on the afternoon of the 20th of October, the fire pressure-pipe burst at a point 50 ft. below top of large tank. The reaction caused by the water escaping through the rupture buckled over the pipe and forced it against the side of the large tank with great violence, breaking it in a second place, bruising and otherwise injuring a section of about 25 ft.

In repairing the damage caused by this accident, it was considered best to use ¼-in. plate, which required the removal of the section of 3-16-in. plate below the point of rupture. According to the above authority, "as the pipe stands the shell has a thickness of ¼ in. for the first 140 ft., 3-16 in. for 60 ft. and ⅛ in. for the remaining 29 ft."

It is a noteworthy fact that the Sandusky standpipe was a pioneer structure of its class, not only in the boldness of the design, but also in the character of the requirements for plate-metal. In reference to the latter, Mr. J. D. Cook, the engineer of the structure, says:

> The plates and rivet rods were manufactured with the greatest care and uniform fidelity by the Otis Iron & Steel Co., of Cleveland, O., and possessed a tensile strength (as shown by numerous and careful tests). ranging from 67,000 to 85,000 lbs., with elastic limit of 30,000 to 45,000 lbs. per sq. in. of sectional area.

No reference is above made to reduction of area or to elongation in the test specimens, but the range in tensile strength about corresponds to the grade of structural steel now designated "high steel." Although the ductile properties of the latter

grade of steel are now regarded as too low in the better practice of tank construction, the use of that or its equivalent grade at the date referred to was undoubtedly a step in advance. Under the strict system of inspection during construction it is improbable that seriously defective material or workmanship of any kind was admitted, and since the nominal working stress in the 3-16-in. plate in which the initial rupture took place was well within the limit of safety, it would seem that the accident was due to some influence brought to bear after completion of the stand-pipe.

The latter seems to have been the case, for it is credibly stated that previous to the accident of Oct. 20, 1878, above described, the inner pipe was inadvertently permitted to be empty while the annular space between the two shells was full of water (a condition against which the designer had expressly advised); this "caused its first collapse, buckling against the walls of the large pipe at opposite sides."

The accident last above described was evidently the more critical of the two, for it not only exposed the greatest inherent weakness of the inner stand-pipe, but also probably developed the flaw to which the later failure was due. The contrast in the existing conditions in the two cases warrants double mention in the classification. The exact date of the earlier accident was not available. It should be observed that the main outer shell sustained no damage in either case.

References.—Sandusky Water Department Report. 1878. Tenth Census, Vol. XVII., Water Supply of Cities, p. 61. Engineering News, Vol. XVI., p. 316 (Nov. 13, 1886). Sanitary Engineer. Vol. XV., pp. 259-260 (Feb. 12, 1887). Manual of American Water-Works. 1889-'90. p. 381. Correspondence with the designing and consulting Engineer (1893).

Cincinnati, O., June 29, 1881.

The Price Hill tank at Cincinnati, O., burst at 10:30 p. m. on June 29, 1881, while being filled for the first time. It was 100 ft. in diameter and 48

ft. high and its capacity to the proposed 46-ft. overflow level was 2,700,000 gallons. The tank had been completed in the fall of 1880, but no test was put upon it until June 17, at which time water was first admitted. In the course of twelve days the water had reached a depth of 39½ ft., when the initial rupture occurred at a point 12 ft. from the bottom of the tank.

The tank consisted of twelve courses of plates, of 4 ft. each, the thicknesses of which were:

Bedplate, ⅝.

Course.	Thickness, ins.	Course.	Thickness, ins.
1	⅝	5	⅜
2	9-16	6, 7	5-16
3	½	8 to 12	¼
4	7-16		

Single lap-riveting was used in all horizontal seams and in the bedplate. The vertical joints were abutted, strapped and double-riveted in the lower six courses, and in the upper half they were double lap-riveted. The $4 \times 6 \times \frac{3}{4}$-in. bottom angle joined the sides and the bedplate of the tank by one and two rows, respectively, of 15-16-in. rivets. Internal stiffening channels and angles were used in the upper courses, they having been added in a supplementary contract.

The plate-metal was required to show by tests of samples from each plate a minimum tensile strength of 65,000 lbs. per sq. in., but no reference to ductility was made. All test pieces met requirements and the records show ultimate resistances of from 71,000 to 90,000 lbs. Test pieces taken from the ruptured plates after the accident showed an ultimate strength of from 70,120 to 75,200 lbs.; an elastic limit of from 39,727 to 44,300 lbs. per sq. in.; and a reduction in area of from 31.4 to 46.5%.

The break started at the top edge of the third course at the junction of the abutting plates of the fourth course, and a fragment 48 ft. long by 24 ft. high burst out and was projected about 100 ft.

The lines of fracture extended from this aperture through both solid plate and riveting, obliquely to the top and vertically downward to the bottom angle. The remainder of the side plates were torn loose from the bedplate, the line of rupture being along the bottom row of rivets in the ⅝-in. plate, and were hurled in a connected mass about 150 ft. in the opposite direction. In the judgment of Mr. A. G. Moore, who took charge of the work as superintendent and engineer upon the completion of the eighth course, the accident was "due to Bessemer steel plates, which, although possessing high tensile and fair ductile properties, would not withstand the aggravation of the excessive and continuous distortions which were caused by the prevalent high winds during its construction, which extended through many months."

References.—Cincinnati "Commercial," June 30, 1881. Engineering News, Vol. VIII., pp. 278-9 (July 9, 1881). Van Nostrand's Engineering Magazine, Vol. XXV., pp. 330-2 (October, 1881). Cincinnati Water Department Report, 1881. Engineering & Building Record, Vol. XVII., pp. 289-90 (April 14, 1888). Proceedings American Water-Works Association, 1888, p. 106. Engineering & Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (October 6, 1888). Manual American Water-Works, 1889-'90, p. 364. Correspondence with Superintendent and Engineer Cincinnati Water-Works Department (1893).

Lexington, Mo., June 22, 1885.

The wrought iron stand-pipe at Lexington, Mo., fell on June 22, 1885, when full of water during its first test. The structure consisted of a tank 22 ft. in diameter by 100 ft. high supported upon six columns 50 ft. high, making the total height 150 ft. These columns were cylindrical in form, made of boiler plate, the five outer ones being 36 ins. and the one center column being 42 ins. in diameter. They were tied together with 2-in. rods and the tank bottom rested upon an I-beam floor system. The foundation under each column consisted of a 5 x 5 x 5-ft. concrete footing with a cap of soft stone. The inlet pipe was supported by connections

with one of the columns. The flange connection in the tank bottom leaked badly and it is believed that the water running down the column undermined the insufficient footings. At the time of the accident no cause for it was made public, but information from a credible source establishes the fact that the failure was due to deficient foundations. The destruction of the stand-pipe was complete.

Descriptions of this accident heretofore published seem to have been based upon the press account, which was grossly in error in several important particulars.

References.—St. Louis "Globe Democrat," June 23, 1885. Engineering News, Vol. XIII., p. 413 (June 27, 1885). Proceedings American Water-Works Association, 1888, p. 106. Engineering & Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). Manual American Water Works, 1889-'90, p. 559. Correspondence with the contractor (1893).

Caldwell, Kan., June 11, 1886.

The 12 × 150-ft. steel stand-pipe at Caldwell, Kan., while in course of construction, was blown down by a cyclone during the night of June 11, 1886. The wind blew from the northwest and the guys giving way, the structure fell toward the southeast. No water had been pumped into it at the time of the accident. Although the structure partially collapsed in falling the damage to it was not serious. After cutting out the rivets and rebending the plates the stand-pipe was rebuilt by using the same material. No indications of weakness have since been observed.

References.—Proceedings American Water-Works Association, 1888, p. 106. Engineering & Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). Correspondence with the Superintendent Caldwell Water Co. (1893). Correspondence with the contractor (1893).

Victoria, Tex., Aug. 20, 1886.

On Aug. 20, 1886, during a severe hurricane, the upper portion of the 16 × 100-ft. wrought iron stand-

pipe at Victoria, Tex., failed by collapsing. The structure was only partially full, the water level being 30 ft. below the top at the time of the accident.

The thickness of the plates was ½ in. for the first 70 ft. and 3-16 in. for the remaining 30 ft. Only the section of thin plate, which was empty, gave way and the collapse occurred on the windward side of the structure. The top edge was stiffened by an angle iron and the stand-pipe was anchored to the foundation by means of brackets.

This accident occurred on the second day of the great gulf coast storm of August, 1886. No gaged observation of the velocity of the wind at Victoria was taken, but it was estimated at 80 miles per hour. The maximum gaged velocity at Galveston was 53 miles per hour, but at Indianola, which was almost totally destroyed, the velocity, at daylight on Aug. 20 had reached 72 miles per hour, when the signal station building blew down, killing the observer. At Seguin, Tex., not far from Victoria, the velocity was estimated at 85 miles, and at San Antonio, 80 miles per hour.

While at the time of this accident to the Victoria stand-pipe it was believed by some that the collapse had been largely due to the formation of a partial vacuum in the empty portion at the top, the fact that the yielding was on the windward side indicates that the cause is to be traced only to the direct impact of the wind. The empty portion swayed to and fro and vibrated very perceptibly before collapsing. The use of needlessly thin plates in the upper portion of the structure was plainly the chief cause of the failure, for the coincidence of an empty stand-pipe during a storm of unusual severity should have been provided for as a probable critical condition. Fig. 1 is a front and Fig. 2 a side view of the collapsed structure.

References.—U. S. Monthly Weather Review, August, 1886, pp. 210-11. Scientific American. Vol. LV., p. 264 (Oct. 23, 1886). Sanitary Engineer, Vol. XIV., p. 616 (Nov. 27, 1886). Proceedings American Water-

FIG. 1. FRONT OF COLLAPSED STAND-PIPE, VICTORIA, TEX.

FIG. 2. SIDE OF COLLAPSED STAND-PIPE, VICTORIA, TEX.

Works Association, 1888, p. 106. Engineering & Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888).

Gravesend, N. Y., Oct. 7, 1886.

The stand-pipe of the Kings County Water Supply Co., located at Gravesend, L. I., burst at 1 p. m., Oct. 7, 1886, while undergoing a preliminary test. In view of the numerous accounts of this accident heretofore published, only the more important features will be here presented.

The Gravesend stand-pipe had a total height of 250 ft., which made it the tallest structure of its class yet built. As usually described, it consisted of a lower and an upper cylinder, 16 × 70 ft. and 8 × 155 ft., respectively, connected by a conical frustum 25 ft. in height. To be exact, however, it should be stated that the lowest section was also a conical frustum, having diameters of 16 ft. and 14.4 ft. at the bottom and at the 70-ft. level, respectively; for it was specified that "for the first 70 ft. the course will be all inside, so at that height the diameter will be lessened by the thickness of the plates. In the taper, the course will be all inside, and above that they will be large and small." A photographic view of the stand-pipe, taken during construction, plainly indicates that the plates were arranged as specified, causing the reduction in diameter above mentioned. Special reference to this condition seems proper in connection with the much-discussed upward thrust due to hydrostatic pressure on the conical surface, which is generally believed to have led to the failure. The relative effect of this reduction in the bottom section, however, was not great.

It is stated that the stand-pipe had previously been filled, when the bedplate was observed to be slightly lifted up about the edges. To counteract this tendency, two sets of braces of 24 each were inserted, being attached to the second course of plates at 6 ft. and 8½ ft. from the base, respective-

ly. These braces were $2\frac{1}{2} \times 1$ in. in section and were bolted to the bedplate and riveted to the sides, leaving about $1\frac{1}{2}$ sq. in. net section.

At points 104 ft. and 224 ft., respectively, above the base, $\frac{3}{8} \times 8$-in. welded collars were placed, from each of which six 1-in. wire rope guys extended to anchors located 80 ft. and 150 ft., respectively, from the stand-pipe. A top angle, $3 \times 3 \times \frac{1}{4}$ in., was used and stiffening Ts were placed in the topmost five courses and at the two extremities of the middle frustum.

The plates consisted of ordinary tank steel and the only requirement specified was that "all plates will be steel, stamped 60,000 lbs. tensile strength." It is stated that a number of plates were rejected by the contractor as being defective, although several defects, whose existence must have been previously known, were found in the ruins. The thicknesses of the plates, of which there were 50 5-ft. courses, were as follows, the bedplate having been $\frac{7}{8}$ in. thick:

Course.	Thickness, ins.	Course.	Thickness, ins.
1	$\frac{7}{8}$	27 to 33........	$\frac{3}{8}$
2 to 6..........	$\frac{3}{4}$	34 to 39........	5-16
7 to 20.........	$\frac{5}{8}$	40 to 45........	$\frac{1}{4}$
21 to 26........	$\frac{1}{2}$	46 to 50........	3-16

The vertical joints were triple-riveted in the first eight courses and double-riveting was used in the remainder of the vertical as well as in all the horizontal seams.

At the time of the accident pumping had been in progress two hours and the water had reached a height of 227 ft., giving a pressure of nearly 100 lbs. per sq. in. at the base. Although it has been claimed that the initial rupture took place in a defective plate in the 14th course, the statement of eye-witnesses that the stand-pipe burst in one of the lower courses seems more credible. Assuming such to have been the case, the rupture seems to have been due to a local defect, since the unit

stresses were not dangerously large at any point. A very plausible theory has been advanced which attributes the failure to the unequal distribution of the upward thrust among the inside braces and the rupture of one or more of them under an excess of strain. While ample provision for the upward tendency might have been made in the original plans, had consideration been given the matter, the design as a whole has justly been pronounced absurd.

References.—Engineering News, Vol. XVI., pp. 255, 264 (Oct. 16, 23, 1886). Sanitary Engineer, Vol. XIV., pp. 494-6, 547 (Oct. 23, Nov. 6, 1886). Scientific American, Vol. LV., pp. 399, 405 (Dec. 25, 1886). Proceedings American Water-Works Association, 1888, p. 106. Engineering & Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). Journal New England Water-Works Association. 1893. Engineering Record, Vol. XXVII., p. 216 (Feb. 11, 1893). Engineering News, Vol. XXIX., p. 243 (March 16, 1893).

Kankakee, Ill., Oct. 14, 1886.

The 20 × 124-ft. wrought iron stand-pipe at Kankakee, Ill., partially collapsed and then overturned during a gale of wind at 9 a. m., Oct. 14, 1886. The tank was empty, having been completed only a week previous to the accident. The storm had begun early in the morning and rapidly increased in force until about the hour above mentioned, when the stand-pipe was first observed to sway slightly, then to lift from the foundation, first on one side and then on the other. An attempt to tighten the anchor rods was without success. In the meantime the sides of the stand-pipe contracted and expanded under the action of the severe gusts, until the windward side collapsed, forming a pocket which extended downward about 25 ft. from the top. With this suddenly increased pressure upon the collapsed top and the more and more violent blows upon the foundation due to the loosened anchor rods, a considerable section of the freshly constructed masonry crushed out on the leeward side, allowing the structure to fall in that

FIG. 3. VIEW OF WRECKED STAND-PIPE AT KANKAKEE, LOOKING NORTHWARD.

direction. The anchor rods on the windward side broke off, while the remainder straightened and pulled out of the masonry.

The wrecked stand-pipe, a view of which is shown by Fig. 3, consisted of 31 courses of plate of 4 ft. each, the thicknesses of which were as follows:

Courses.	Thickness, ins.	Courses.	Thickness, ins.
1	11-16	14 to 16........	3/8
2 to 4...........	5/8	17 to 19.........	5-16
5 to 7..........	9-16	20 to 22.........	1/4
8 to 10.........	1/2	23 to 25.........	3-16
11 to 13........	7-16	26 to 31........	1/8

Only the section of 1/8-in. plate collapsed previous to the fall of the stand-pipe.

The top stiffening angle was $3 \times 3 \times \frac{1}{2}$ in. and the bottom angle iron was $6 \times 6 \times \frac{1}{2}$ in., the latter being single-riveted to the side plates, and double-riveted to the bedplate. All vertical joints were double and the horizontal joints were single-riveted, the sizes of the rivets being as follows:

7/8-in. rivets in bottom angle-iron,
3/4 " " " courses 1-16,
5/8 " " " " 17-22,
3/8 " " " " 23-25,
5-16 in. " " " 26-31.

The riveting is said to have been "thoroughly" done and no charge has been made that material of inferior quality was used in the structure.

The foundation was 21 ft. in top diameter and 7 ft. deep, being composed of concrete and stone masonry. The anchorage consisted of six 1½-in. wrought iron rods, the upper ends of which passed through cast iron lugs secured to the middle of the second course of plates by six 7/8-in. rivets each. Each rod was adjustable by means of a nut above the lug, and its lower end, instead of passing vertically to a large washer beneath the foundation, merely reached 2 ft. deep into the masonry, where an additional 2 ft. of the rod, bent at right angles, constituted its sole anchorage.

The maximum velocity of the wind was estimated at 60 miles per hour, although the observed velocities at neighboring points were considerably less than that above stated. According to the U. S. "Monthly Weather Review," October, 1886, the storm in question was general in extent, originating in Kansas and following a northeasterly course to the Gulf of St. Lawrence. The maximum measured velocities at various points were:

Springfield, Ill.,	6 a. m.,	34	miles per hour,
Chicago, "	1 p. m.,	36	" " "
Detroit, Mich.,	3 p. m.,	52	" " "
Buffalo, N. Y.,	8 p. m.,	70	" " "

It is quite evident that the failure was in the main due to the grossly insufficient provision for anchorage, although without doubt the collapse in the thin top plates, the green condition of the masonry, and the absence of water in the stand-pipe also conspired materially to the same end. It would even appear, considering only the poor use that was made of the available anchorage, that the six rods were an afterthought, or if wind pressure had received consideration at all in designing the structure, the very unsafe assumption of a full tank may have been made. At any rate the accident is justly classed as due to errors of design rather than to defects in material or workmanship.

References.—Kankakee "Gazette," Oct. 15, 1886. Engineering News, Vol. XVI., p. 287 (Oct. 30, 1886). Sanitary Engineer, Vol. XIV., p. 519 (Oct. 30, 1886). Scientific American, Vol. LV., p. 264 (Oct. 23, 1886). Monthly Weather Review, October, 1886, pp. 276-7. Sanitary Engineer, Vol. XV., p. 113 (Jan. 1, 1887). Report Illinois Society Engineers and Surveyors, 1887. p. 149. Proceedings American Water-Works Association, 1888, p. 106. Engineering and Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News. Vol. XX., p. 272 (Oct. 6, 1888). Journal New England Water-Works Association, 1893. Engineering Record, Vol. XXVII., p. 216 (Feb. 11, 1893). Engineering News, Vol. XXIX., p. 243 (March 16, 1893). Correspondence with an eye-witness (1893).

Asheville, N. C., March 28 (?), 1887.

The steel stand-pipe at Asheville, N. C., having a diameter of 45 ft. and a height of 60 ft., partially

collapsed during a severe windstorm toward the close of March, 1887. The structure had just been completed, but had not been tested and put into service.

The plates were ¼ in. thick in the upper 20 ft., ⅜ in. in the middle 20 ft. and 7-16 in. thick in the lower 20 ft. The top angle was $3 \times 3 \times \frac{1}{2}$ in.

An eye-witness states that "a gale blew in and jammed the upper courses on the west side over against the opposite wall of plates. The builders secured an eyebolt to the indented portion of the pipe, and, with the aid of a windlass rigged on the slope of the hill, pulled the plates into shape 'as good as ever,' only a slight wrinkle remaining to show where the collapse had stopped." Unfortunately, no record of the velocity of the wind at the time of the failure is available.

Considering the exposed location and the exceptionally large diameter of the stand-pipe, the small provision for top stiffness forcibly suggests the cause of the collapse.

(Note.—This stand-pipe failed entirely on Jan. 22, 1893, which accident will be described in its proper order.)

References.—Monthly Weather Review, March. 1887, p. 89. Asheville "Citizen," Jan. 23. 1893. Correspondence with an eye-witness (1893). Correspondence with local authorities (1893).

Plattsmouth, Neb., April 9, 1887.

The 25×80-ft. steel stand-pipe at Plattsmouth, Neb., partially collapsed while empty during a severe windstorm on April 9, 1887. The stand-pipe had been in use but a short time and had been emptied on the morning of the above mentioned date for the purpose of repairing a leak in the inlet pipe. The stand-pipe rests upon a concrete foundation located upon an eminence about 180 ft. above the Missouri River. The anchorage consisted of four 2-in. rods passing through the foundation and

riveted to the first course of plates. The thicknesses of the plates were as follows:

Courses.	Thickness, ins.	Courses.	Thickness, ins.
1	7-16	9, 10............	9-32
2	13-32	11, 12............	¼
3, 4............	⅜	13, 14............	7-32
5, 6............	11-32	15 to 20..........	3-16
7, 8............	5-16		

The top angle was 2×2 ins., punched for riveting a cornice, which was not put on.

The following description of the accident has been communicated by Mr. C. W. Paine, of Cleveland, O., who had charge of the construction of the Plattsmouth water-works:

At about 9 a. m. the pipe was empty and disconnected. A strong wind was blowing and increasing in force. Noticing that the pipe was swaying somewhat and the angle at the top bending, I directed the foreman to fasten a rope to it as a guy. While this was being done one of the 2-in. anchor bolts broke (a flaw in the iron being noticed). The pipe swayed out of the perpendicular several feet and began rocking back and forth on its base. As soon as possible the rope guy was set up taut with pulley blocks and the rocking motion checked somewhat.

As the wind increased in violence the angle at the top broke in several places, the windward and leeward sides approached each other frequently, and after a time came nearly if not quite together. The diameter at right angles to the direction of the wind, of course, became considerably greater at such times. This bending or caving in of the pipe extended 13 courses from the top. At some risk a rope was made fast to the top of the pipe on the windward side and it was pulled out and held in place. As soon as repairs could be made to the inlet pipe water was pumped in and the standpipe was filled without any repairs. It leaked but very little, much less than many new pipes. A new and heavier angle was afterward put at the top and four-wire guys were put on.

No definite measurement of the maximum wind velocity was secured, as the wind gage at the Plattsmouth bridge was disabled during the same storm. The maximum velocity of the wind at Omaha, some 20 miles up the river, as shown by the record of the self-registering gage at that place, was but 36 miles per hour, but the extreme velocity at the

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successive

stand-pipe must have exceeded that figure considerably. It has been suggested that a measure of the maximum force of the wind may be found in the failure of the windward anchor bolt or in the tilting of the empty tank on its leeward edge. Nothing positive can be based upon the bolt failure on account of the flaw already mentioned, but a consideration of the force necessary to tilt the standpipe about its leeward edge indicates that the maximum velocity was about 70 miles per hour. However, the uncertainty of the extent to which the partial overturning may have been the result of accumulated force due to the coincidence of consecutive gusts and vibrations makes such an estimate quite unreliable. The latter fact leads to the conclusion that although stiffness in the upper portion of the structure was not liberally provided for, the causes leading to the final collapse are primarily traceable to the breakage of the anchor bolt and the consequent rocking to and fro on the foundation.

References.—Proceedings American Water-Works Association, 1888, p 106. Engineering and Building Record, Vol. XVII., p. 327 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). Correspondence in 1893 with: The designing engineer; the constructing engineer; the wind gage observer, Plattsmouth, and with the forecast official, Omaha.

Newport, Ark., May 19, 1887.

On May 19, 1887, the elevated wooden tank of the Newport (Ark.) Water Co. burst when filled for the first time. The tank was 24 ft. in diameter by 20 ft. height of stave, and was supported by a timber frame 100 ft. high, making the total height 120 ft. The staves were of 3-in. cypress lumber, and the hoops, 13 in number, were 3½ ins. wide with ⅞-in. drawbolts. The accident was due to the failure of a hoop, probably from overstraining it in an effort to stop leakage. Besides the entire destruction of the tank and frame, the pump house and a dwelling house were wrecked.

References.—Proceedings American Water-Works Association, 1888, p. 106; Engineering and Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). Correspondence with the president of the Newport Water Co (1893).

Franklin, Mass., Oct. 27, 1887.

This stand-pipe, which failed at 2:10 a. m., on Oct. 27, 1887, consisted of a wrought iron tank with a diameter of 40 ft. and a height of 35 ft. elevated upon a 45-ft. brick tower, making the total height 80 ft. The tank, as originally built, rested upon a rubble foundation at the surface of the hilltop, but in order to secure better fire service it had been raised upon the brick tower a few weeks previous to its fall. When the accident occurred the tank had 25 ft. of water in it and the pumps had been running for about eight hours at a uniform rate. When the structure fell the pressure at the pumping station dropped from 105 to 60 lbs. per sq. in., which was accompanied by a terrific increase in the speed of the engine.

The work of raising the tank had begun about eight weeks before the accident occurred. After emptying the tank, 18 recesses were cut into the circumference of the foundation far enough to permit that number of jacks to be placed under the rim of the tank bottom. After lifting the tank by means of these jacks and the use of blocking, to a height of 5 ft., a timber floor of 5½-in. hard pine planks, supported by a radial system of 16 9-in. I-beams was placed under the tank bottom. Twenty-three jacks were placed under a hexagonal timber framework, which supported the I-beams just inside the outer brick wall. The outer wall was 16 ins. and the inner wall 12 ins. thick. The mortar consisted of cement, lime and sand, the proportions of which are not recorded. Four weeks after starting the brickwork, the walls were completed to their final height, and only a few days elapsed until the tank was allowed to partially rest upon

them. When the structure fell the bottom of the tank sill had a bearing upon the blocking and the jacks.

The tank was constructed with seven courses of wrought iron plates, of which the lower four were 5-16 and the upper three courses were ¼ in. thick. The bottom of the tank was ⅜ in. thick, and the bottom angle iron was 4 x 4 x ½ in. At the top was a 2-in. angle and midway of the height was placed on the inside a 3-in. T-iron stiffener. Single-riveting was used throughout.

The destruction of the tank was complete, but no evidence indicating a defective condition in it, previous to the accident, could be found. The main body of the side plates fell in an unrolled mass on the original foundation, and the bottom was torn into five fragments, which were projected to distances of from 50 to 200 ft. in various directions.

The wrecked brickwork indicated very inferior quality, and it is believed that the failure was due solely to the weakness of the walls. It is stated that at least 50% of the bricks showed little or no adhesion of mortar.

References.— Sanitary Engineer, Vol. XVI., pp. 641, 643 (Nov. 19, 1887). Engineering News, Vol. XVIII., p. 324 (Nov. 5, 1887). Proceedings American Water-Works Association, 1888, p. 106. Engineering and Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). Journal New England Water-Works Association, 1893. Engineering Record, Vol. XXVII., p. 216 (Feb. 11, 1893). Engineering News, Vol. XXIX., p. 243 (March 16, 1893).

Seneca Falls, N. Y., Oct. 27, 1887.

The steel stand-pipe at Seneca Falls, N. Y., failed by a rupture in one of the side plates at 3 p. m. on Oct. 27, 1887. It had been in use since July 1 preceding, but had given no visible evidence of the defect which resulted in its destruction after only four months' actual service. The capacity of the stand-pipe was about 637,000 gallons and its height was 130 ft. The diameter at the bottom was 30 ft. and at the top 27 ft. 9 ins., the reduc-

tion being made in the construction by placing each successive cylinder inside the next lower one. There were 30 courses of plate, of which the lower eight were ⅝ in. thick, the next eight ½ in., the next seven ⅜ in. and the upper seven were ¼ in. thick. In the bedplate, thicknesses of ⅜ and ⅝ in. were used, the thicker plates being placed about the circumference.

The riveting, which was done in a first-class manner, was double in the vertical and single in all the horizontal seams. In the latter the pitch varied from 3 ins. in the thicker to 2¼ ins. in the thinner plates; the double riveting was staggered with 3 ins. between rivets in each row and the rows were 3 ins. apart. All rivets were ⅞ in. diameter and the rivet holes were punched and not reamed. No anchorage whatever was provided either in the form of guys or anchor rods.

The foundation was constructed of rubble masonry of very inferior quality. A pit about 2 ft. deep was dug into the clay and, of three courses, only the top one was laid in mortar, Rosendale cement being used. The bottom of the tank was first laid directly on the top of the foundation without being bedded in mortar, but after four courses of plates had been riveted on, the tank was lifted and a layer of Rosendale cement mortar 3 ins. thick was put under the bedplate.

Water was flowing over the top of the stand-pipe when the failure occurred. The first rupture seemed to take place on the northwest side about 8 ft. from the bottom. The lower 40 ft. was torn into a number of pieces, which were projected to considerable distances from the foundation. The top section of 90 ft. fell in a northwestward direction, being carried nearly 30 ft. clear of the foundation. Several defective plates were found in the ruins, one particularly defective fragment being thrown some distance westward from the upper section. The fractures in general indicated an inferior grade

of steel, marked brittleness being displayed; they also gave signs of the steel having been under-worked in the process of its manufacture. There were many cracks of a brittle character in the body of the plates. but fractures along rivet lines were more common. With a full tank the 15-16-in. rivet holes and the 3-in. pitch in the ⅝-in. bottom course of plates gave the excessive strain of 23,000 lbs. per sq. in. in the net section and the rivet shear was 25,000 lbs. per sq. in.

It should be observed that this stand-pipe was both designed and constructed without engineering advice of any sort and that no provision whatever was made for inspection of the structural materials. The cause of the failure has been assigned to a lack of uniformity in the quality of the steel and to the existence of flaws in the plates, but if consideration be given to the low margin of safety above mentioned the defective design should share the responsibility.

References.—Sanitary Engineer, Vol. XVI., pp. 643, 683 (Nov. 5, 12, 1887). Engineering News, Vol. XVIII., p. 337 (Nov. 12, 1887). Proceedings American Water-Works Association, 1888, p. 106. Engineering & Building Record, Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). Journal New England Water-Works Association, 1893. Engineering Record, Vol. XXVII., p. 216 (Feb. 11, 1893). Engineering News, Vol. XXIX., p. 243 (March 16, 1893).

Thomasville, Ga., Dec. 6, 1887.

This stand-pipe, as first designed, was to consist of a 70-ft. brick tower supporting a wrought iron tank 25 ft. in diameter and 30 ft. high, the total height thus to be 100 ft. As planned and partly executed the brick tower consisted of an interior pier 6 ft. in diameter surrounded by an outer circular wall having eight buttresses. The brickwork was nearing completion when some bracing that had been placed between the center pier and the outer wall was removed. The pier fell, carrying with it a section of the outer wall, including one of the buttresses, as shown in Fig. 4. It was first thought

FIG. 4. COLLAPSED TOWER AT THOMASVILLE, GA., LOOKING SOUTHEAST.

that the accident was due solely to vibrations caused in hoisting brick to the top of the pier, but it was afterward found that there had been some inequality in the settlement of the foundations which may have had some influence in causing the failure. However, this inequality in settlement may have been one of the effects rather than a cause of the failure. The tank had not been erected at the time of the failure, and consequently the damage to property was limited to the brickwork itself. Four men, one of whom was the contractor, were killed and four others seriously injured in the accident.

References. — Engineering & Building Record, Vol. XVII., pp. 22, 40 (Dec. 10, 17, 1887). Engineering News, Vol. XVIII., p. 428 (Dec. 10, 1887). Proceedings American Water-Works Association, 1888, p. 106. Engineering & Building Record. Vol. XVII., p. 337 (May 12, 1888). Engineering News, Vol. XX., p. 272 (Oct. 6, 1888). Manual American Water-Works, 1889-'90, p. 326. Correspondence with Water-Works Co., Thomasville.

Greencastle, Ind., Jan. 21, 1889.

The 22 × 140-ft. wrought iron stand-pipe at Greencastle, Ind., was damaged by falling ice Jan. 21, 1889. Following a period of very cold weather the ice had been heard to fall in the stand-pipe and the next morning the pumps had been started slowly with a view to loosening it. An unwarranted rise in the pressure, considering the speed of the pumps, caused some apprehension, so the stand-pipe was closed and water was pumped directly into the mains until the weather permitted the pipe to be drained. The drainage had not proceeded far when it was arrested by a loud report which indicated the danger in lowering the water before the ice had melted sufficiently to clear inside obstructions. Upon removal of the manhole after the pipe was emptied it was found that the ladder which had been constructed upon the inside had been entirely broken down and the rivets holding it had been sheared off. No further damage could be dis-

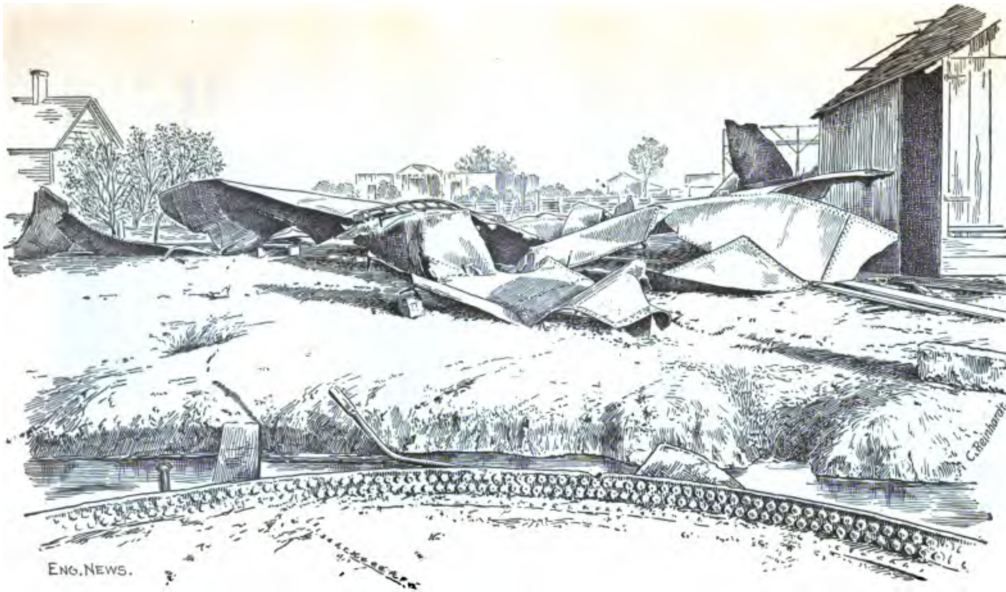

FIG. 5. TEMPLE STAND-PIPE, LOOKING EAST AT PORTION OF LOWER PLATES.

The quality of plate metal specified was "steel, 60,000 lbs. tensile strength, free from flaws and blisters," but no structural tests were called for or were made during construction of the stand-pipe.

The lower third of the stand-pipe, consisting of the first eight courses of plate, was torn asunder and the larger portion of it, clinging together, was thrown in a distorted mass about 60 ft. to the eastward; several pieces were projected to considerable distances in other directions, and a few fragments of the first course of plates held fast to the bottom angle. A section consisting of nearly the entire upper two-thirds of the stand-pipe fell to the westward, clearing the foundation and collapsing upon striking the ground. Figs. 5 to 8, inclusive, are views of various parts of the pipe.

The line of fracture around the base occurred either in the bend of the bottom angle or in the ⅝-in. side sheets along the upper line of the lower double row of riveting, mainly the latter. Most of the breaks in the angle itself appeared to have been caused by impact from falling plates, as shown by the crushed and brightened metal. Although the bedplate was thus somewhat protected, it did not entirely escape damage, for several distinct indentures and one large gash were produced in it, the latter being especially conspicuous. This incision was located near the southeast edge, as shown in Fig. 8, and extended through the bedplate and into the concrete to a depth sufficient to allow a considerable block of the latter to be washed out. After a careful search the particular plate which thus punctured the bedplate was found near the southeastern outskirts of the ruins, its identification being based upon the bruised and rolled-up edge covered with particles of concrete. Although the exposed edges of the foundation were much crushed and scoured, the original layer of cement mortar upon which the bedplate had been set was not appreciably disturbed, for even the bearing of

FIG. 7. TEMPLE STAND-PIPE, LOOKING WEST THROUGH UPPER PORTION.

the outer circle of rivets remained firm. The anchor rods were bent down radially, several of them breaking in the threaded portion.

The lines of fracture and general behavior of the lower and thicker plates indicated a distinctly brittle and almost crystalline character, although the numerous curled and rolled-up edges to be observed in the ruins of many of the thinner plates plainly suggested their ability to stand a severe cold bend test. The riveting, which in general seemed to have been fairly well done, revealed its weakest feature in the excessive length of single riveting which failed by rivet shear. The rupture of double-riveted joints occurred mainly along the reduced plate section. No well-defined flaws or defects were found, except a narrow line of rust, discovered within a few hours after the failure, along the outer edge of the otherwise bright fracture in the lowest course at the bottom angle. This fact is of interest in connection with certain loud snapping sounds which had been heard coming from the stand-pipe after it was filled.

It is credibly stated that this stand-pipe was originally designed and the plates punched for use at another point, the original plan, however, calling for a height of 110, instead of 120 ft., and that upon deciding to ship the plates to Temple, Tex., two courses (10 ft.) of "tank steel" were added at the bottom.

The failure was at first popularly ascribed to the malicious use of dynamite on account of the incision in the bedplate, but this theory ceased to be entertained with the discovery of the cutting edge above mentioned. Prof. J. B. Johnson, who personally investigated the failure and subsequently made tests of the steel plates, thus refers to the quality of metal in the two lower courses:

The tensile strength was 75,000 lbs.; but they were so brittle that when the 2½-in. wide test specimens, which were sheared off the sheets and slightly bent in the shearing were straightened in the rolls, several of

FIG. 8. · INCISION IN BED PLATE OF TEMPLE STAND- PIPE.

them broke short off, like cast iron. The computed stress per square inch of net section in a bottom ring vertical seam was only about 17,000 lbs. when it failed.

Since sheets possessing qualities such as those above described could not, with reason, be expected to pass through the process of punching and bending without damage to the metal, the failure seems plainly due to defects originating in this manner. While, as already stated, no structural tests were required, the working and punching of the plates must, of necessity, have revealed the dangerous qualities above mentioned, which should have led to their rejection. The projection of the lower portion to the eastward and the toppling of the upper section to the westward indicate that the initial rupture occurred upon the latter side of the stand-pipe*

References.—The Temple "Sun," Oct. 25 1890. Engineering News, Vol. XXIV., p. 385 (Nov. 1, 1890). Scientific American, Vol. LXIII., p. 353 (Dec. 6, 1890). Engineering News, Vol. XXV., p. 351 (April 11, 1891). Correspondence with the engineer who investigated accident (1893). Personal examination (Oct. 25, 1890).

Defiance, O., Feb. 8, 1891.

(On Feb. 8, 1891, some seven weeks before the final failure of the Defiance stand-pipe, described below, ice was blown over its top when the pumps were suddenly started. A description of this accident and of the damage sustained to an already defective plate near the base is given in connection with the record of the final failure, which occurred on March 29, 1891.)

Stevens Point, Wis., March 13, 1891.

Ice fell in the 20 x 140-ft. wrought iron stand-

* Since the above was put in type, a careful chemical analysis of a sample, secured by the writer in person, from the first course of plates of the Temple stand-pipe has been made by Mr. A. H. White, of the Chemical Department, University of Illinois. Four tests for phosphorus by two methods gave results ranging from 0.152% to 0.158%, averaging 0.155%. This clearly stamps the "tank" steel used in the two lower courses as "high phosphorus" and accounts for the objectionable physical qualities above described.

pipe at Stevens' Point, Wis., on March 13, 1891, and caused a plate in the 18th course from the bottom to bulge seriously in its upper right-hand corner. The damage also extended to the breaking of rivets in the adjoining vertical and horizontal seams, and the plate immediately above was cracked along a line of rivets, while the seam to the right was spread apart. The damaged plates were ⅜ in. thick The daily pumpage at the time of the accident was about 200,000 gallons.

This stand-pipe was constructed of wrought iron plate, tested to 48,000 lbs. tensile strength; the thicknesses for various heights were as follows:

Height, feet.	Thickness, inches.	Height, feet.	Thickness, inches.
0 to 20	10-16	80 to 100	6-16
20 to 40	9-16	100 to 120	5-16
40 to 60	8-16	120 to 140	4-16
60 to 80	7-16		

The riveting in the lower 80 ft. is double and in the upper 60 ft. is single. The anchorage is provided for by bolts attached to plate brackets. The foundation rests upon a granite ledge and has diameters of 44 and 30 ft. at the bottom and top, respectively; the depth is 16 ft., of which the lower 8 ft. is concrete and the upper half is granite rubble. The angle iron at the top of the structure is 3 x 3-in., placed upon the inside.

The accompanying view, Fig. 9, shows the method of repairing the damaged portion of the stand-pipe. The details were planned and executed by Mr. W. O. Lamoreux, Superintendent of the Stevens' Point Water Co., through whose courtesy the view and the following description were obtained:

We built a swinging scaffold or staging which we hoisted to the break, 85 ft. (this was, of course, suspended from the top of the pipe), and put a 5 x 5-ft. patch on after cutting out the injured portion. The holes were punched and the plate bolted on with one man inside; the next thing was to heat the rivets outside, pass them through a hole (prepared for the purpose, and afterward tapped and plugged) to the man inside, who immediately put them in the rivet holes and held them for two boilermakers to rivet down,

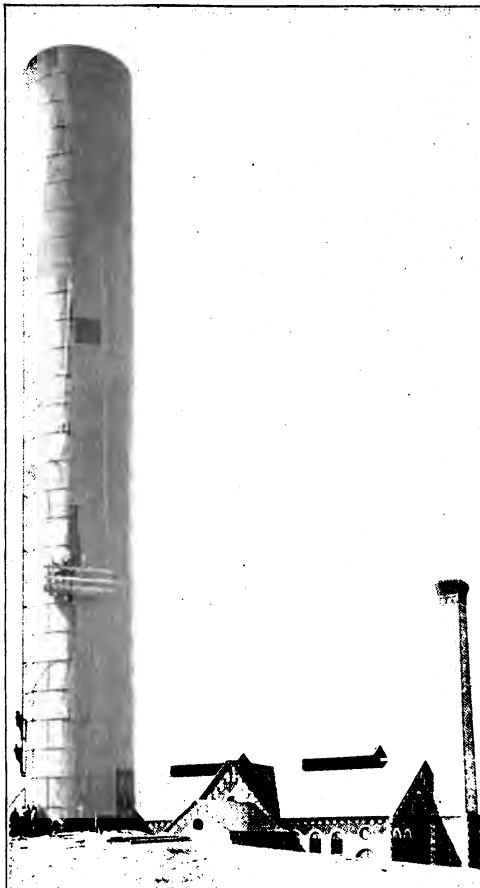

FIG. 9. METHOD OF REPAIRING STAND-PIPE AT STEVENS POINT, WIS.

after which we pumped the man inside to the surface and he came down the ladder. The job was a success, and cost but $275.

This accident, while apparently of trivial importance, is in reality worthy of the closest study along the following lines:

(1) The cause is known with certainty to have been the fall upon the water of a quantity of ice which had been lifted to and lodged against the top angle iron.

(2) The conditions of weather had been as follows: A protracted cold period, during which a wall of ice nearly the entire height of the stand-pipe had formed, succeeding which came a rise in temperature of sufficient extent and duration to thaw the huge tube of ice free from the wrought iron shell, and to allow it to rise against and slightly above the top angle iron; then a sudden freeze occurred which caused the ice to adhere to and remain suspended by the top angle until a second very rapid rise of temperature loosened the grip above and allowed the ice to fall.

(3) The necessity for extraordinary caution in the use of the stand-pipe during such a critical period.

(4) The structural metal was wrought iron.

(5) In view of the dangerous practice of using stand-pipes which are known to have defective plates, the exceedingly cheap and effective method of repairs adopted at Stevens' Point deserves extended notice and use.

It is of further interest in this connection to notice that the unusually heavy ice formation in the Stevens Point stand-pipe, due to its exposed location, had afforded an experience from which observations of much value may be drawn. During mid-winter ice forms from the bottom up, to a thickness of 2 to 3 ft., according to the severity of the winter, and in the milder seasons the ice tube often melts away at the base to a height of some 40 ft. under the action of the water before breaking

up. Previous to the accident above described, the ice had frequently become lodged on the angle iron at the top and had fallen, but no damage resulted because of the slight fall. Since the accident, however, a repetition has been prevented by constantly keeping the water level well up at such times, this being "the only safe procedure after the ice is loosened from the pipe." The free movement of the ice after melting loose is seriously interfered with by the angle iron at the top rim being placed inside, but upon several occasions the melting has been sufficient to allow the great tube of ice to pass the angle iron and to protrude as much as 20 ft. above the top of the stand-pipe.

Another source of trouble has been found in the frequent formation of an air tight cap of ice, requiring extreme caution in starting the pumps so as to force an opening gradually, and in case of a fire or other heavy demand upon the gravity supply, the pressure has been found to fall very rapidly. At such times a distinct whistling sound, due to the rapid passage of air through a small opening in the ice-cap has often been heard.

References.—Engineering Record, Vol. XXIII, pp. 288 (April 4, 1891). Correspondence with the superintendent of the Stevens Point Water Co. (1893).

Defiance, O., March 29, 1891.

The 22 x 140-ft. steel stand-pipe at Defiance, O., burst at 12:10 p. m., March 29, 1891. At the time of the failure the gage indicated a height of 139 ft. of water in the pipe and the pumps were running. Two defects in a plate of the second course were known to exist before the stand-pipe burst. The first of these, consisting of a crack between two vertical rows of rivets, developed when the stand-pipe was filled the first time after its completion in January, 1889, more than two years previous to the final failure. Sediment soon stopped the leakage from this crack and nothing was done toward removing or reinforcing the defective part.

Some seven weeks previous to the date upon

which the stand-pipe burst, on the morning of Feb. 8, the indicated water level being 60 ft., the pumps were started. An explosion followed and large quantities of ice were projected to a height of 10 ft. above the top, accompanied by a violent rocking of the stand-pipe and a contraction in the second course of plates. A careful examination showed a second crack in the opposite end of the defective plate, above mentioned. This second defect started in a rivet hole at the upper edge of the plate and was about 6 ins. long. As in the previous instance, no action was taken either to repair the damage or to stop the use of the stand-pipe until made safe. At the time this phenomenon occurred inquiry was made into the probable cause and it was quite generally believed that the ice had been projected over the top of the stand-pipe from a considerable distance below. Experience elsewhere, however, suggests that a sheet of ice had formed near the top, and that a thaw had allowed the ice to rise against, and perhaps slightly above, the top angle, to which it froze, forming an air tight cap. The thawing weather weakened this cap, which probably gave way upward owing to the rapid increase of air pressure from below due to the pumping, producing the explosive sound heard at the time. The impact caused by a portion of the mass of ice striking the water surface would have caused the vibration.

The final failure, which occurred after three hours' of continuous pumping, when the stand-pipe was practically full, seems to have been due to the cracked plate in the second course. This and the first course of plates were torn into several fragments and projected considerable distances. The upper portion fell clear of the foundation, and the bedplate was moved 15 ins. No crystallization was visible in the plate fractures and most of the lines of rupture were in the solid plate. Very few rivets were pulled out and none were sheared.

The steel plates varied in thickness from ⅝ in.

in the bottom course to ¼ in. in the top course, decreasing 1-16 in. for each 20 ft. The foundation was of stone masonry 40 ft. in diameter and 15 ft. deep, and the anchorage consisted of eight 2-in. bolts secured to plate brackets.

Ice having a thickness as great as 18 ins. was found in the ruins, but it is supposed to have been floating freely in the stand-pipe, as the weather had been quite warm for several days. Although the second flaw was developed by the ice, as above described, the existence of a previous crack fixes much of the cause of the accident upon the defective steel plate. However, the real responsibility for the failure lies in the negligent policy which permitted the use of a structure known to be in a critically dangerous condition.

References.—Engineering Record, Vol. XXIII., pp. 288, 309-10 (April 4, 11, 1891). Engineering News, Vol. XXV., pp. 313, 343 (April 4, 11, 1891). Journal New England Water-Works Association, 1893. Engineering Record, Vol. XXVII., p. 216 (Feb. 11, 1893). Engineering News, Vol. XXIX., p. 243 (March 16, 1893).

Nappanee, Ind., Aug. 25, 1892.

A wooden water-works tank 24 ft. in diameter and 20 ft. high, supported upon a 70-ft. timber frame, burst during test at Nappanee, Ind., Aug. 25, 1892. The failure is supposed to have been due to overstraining the wrought iron hoops, inasmuch as the accident occurred immediately after the contractor had tightened the hoops to stop the leakage. The tank and supporting frame were destroyed.

References.—Engineering News, Vol. XXVIII., pp. 193, 251 (Sept. 1, 15, 1892). Correspondence with local authorities, Nappanee (1893).

Wheatland, Ia., Jan. 16, 1893.

An elevated wooden tank, 20 × 20 ft., burst on Jan. 16, 1893, at Wheatland, Ia. It was built of pine staves and the hoops are said to have been of wrought iron. Although the tank had been completed about two months it had not been accepted from the contractor. It was about two-thirds full

of water and contained a small quantity of ice at the time of the accident.

The cause of the failure is stated to have been the overstraining of the hoops in an effort to stop the leakage. It is probable, however, that the prevailing low temperature had some influence upon the metal of the hoops.

References.—Engineering News, Vol. XXIX., p 73 (Jan. 26, 1893). Engineering Record, Vol. XXVII., p. 171 (Jan. 28, 1893). Correspondence with local authorities (1893).

Asheville, N. C., Jan. 22, 1893.

(Note.—See description of the partial collapse of the Asheville stand-pipe which occurred during a windstorm in March, 1887.)

The steel stand-pipe at Asheville, N. C., burst and fell early on the morning of Jan. 22, 1893. It had for some time been used only to hold a reserve supply for fire service, and at the time of its failure contained about 45 ft. of water. A period of unusually cold weather had caused a tube of ice having a thickness of 7 or 8 ins. to form inside the stand-pipe, but a few days immediately preceding the accident the weather had been somewhat warmer. During the colder period above mentioned, persons in the vicinity heard loud cracking sounds which seemed to originate in the stand-pipe. These signs caused much apprehension because of a break which had developed about two years before in the bottom angle, but which had not been reenforced in any manner, the only action taken being to drop bags of sand into the stand-pipe to stop the leakage. The night of the failure was marked by a considerable reduction of temperature.

The diameter of the stand-pipe was 45 ft.; the height, 60 ft.; the bedplate was ⅝ in. thick and the side plates, consisting of 12 courses of 5 ft. each, had thicknesses as follows:

Courses.	Thickness, ins.	Courses.	Thickness, ins.
1 to 4	7-16	9 to 12	¼
5 to 8	⅜		

The angle joining the bedplate to the first course

was $4 \times 4 \times \frac{5}{8}$ in. and the top stiffening angle was $3 \times 3 \times \frac{1}{2}$ in., placed inside. The stand-pipe rested upon a stone foundation and its capacity was 713,000 gallons.

Almost the entire stand-pipe clung together and fell in a flattened mass to the southward, as shown in Figs. 10 and 11, clearing the foundation about 10 ft. The west half of the upper six courses was doubled under, but otherwise the plates were spread out in a single layer. The principal line of fracture could be traced passing from a point at the base on the northwest, spirally upward to the right, to a point near the southeast at the top; the fracture about the base occurred mainly in the bend of the angle. Aside from the crack in the bottom angle above mentioned, nothing resembling a flaw could be found in the ruins. However, the fact that the structure toppled and fell directly to the southward suggests that the initial rupture occurred upon that side.

The cause of this accident has been ascribed to the formation of ice in the stand-pipe, but the existence of a grossly neglected flaw should bear at least an equal share of the responsibility; for, although simple hydrostatic pressure might have been withstood through an indefinite period, it is also true that the conditions of weather attending the failure were not unusually severe. A careful consideration of all features of the case suggests the following explanation:

The relatively constant stage of water in the stand-pipe due to its restriction to the demands of fire service would allow the ice to form a tube having an equal thickness from the base to the level of the water. During the few warmer days preceding the accident, the heat of the sun must have caused the ice to melt more or less where it came in contact with the metal shell on the south half of the stand-pipe, and as the junction of the ice with the bedplate was doubtless watertight, for the reason above stated, the water trickling down

FIG. 10. VIEW OF STAND-PIPE FAILURE AT ASHEVILLE, N. C., LOOKING NORTH.

would fill the melted space to a level of probably nine-tenths of the total height of the ice tube. With the fall in temperature on the night of the failure, the pocket of water would probably re-freeze at the top first, after which the remaining water, being confined, would develop enormous energy, retaining its liquid form except as available space was gained by compressing the ice tube or extending the plates of the stand-pipe, as in the familiar

FIG. 11. VIEW OF STAND-PIPE FAILURE AT ASHEVILLE, N. C., LOOKING NORTHWEST.

bomb-shell experiment. Simultaneously with the above, the falling temperature would tend more and more to contract the metal shell until, at the coldest hour of the night, the climax was reached in the failure of the structure. Whether the initial rupture occurred in lifting the stand-pipe by breaking the bottom angle or in the failure of a vertical riveted joint, is uncertain, but the latter would seem the more probable. In either case, however,

assuming the above theory to be correct, the structure might have been expected to fail on its south side.

It is credibly stated that the stage of water in the tank was habitually so low that the plates vibrated with more or less violence under the action of the strong winds, resulting, as was supposed by some, in the injury to the bottom angle already mentioned as having occurred some two years previous to the final disaster. In order to reduce this vibratory tendency guys were added at that time, and, although the water level continued low, the trouble from the wind, above mentioned, is said to have been reduced.

References.—Asheville "Citizen," Jan. 23, 1893. Engineering News, Vol. XXIX., p. 73 (Jan. 26, 1893). Engineering Record, Vol. XXVII., p. 191 (Feb. 4, 1893). Correspondence with the city engineer and with the local authorities of Asheville (1893).

Maryville, Mo., Feb. 28, 1893.

On Feb. 28, 1893, at 12:10 p. m., the $18\frac{1}{2} \times$ 135-ft. steel stand-pipe at Maryville, Mo., burst and fell. The severe weather during a few weeks preceding the accident had caused the formation within the stand-pipe of an immense body of ice in the form of a tube, the thickness of whose walls ranged from $2\frac{1}{2}$ ft. at the bottom to 4 ft. near the top. The accumulation was greatest some 30 ft. from the top, at about the average line of the daily fluctuations in the water-level. The temperature, which had risen some 60° several days previous, fell suddenly on the evening preceding the accident to +8° F., but rose again so rapidly during the morning of the day of the accident that thawing was in progress before noon-time. The water level at the time of the failure was said to be 100 ft. above the base, which was equivalent to about 85,000 gallons, the average reduced diameter being taken at 12 ft. It was estimated that a fresh supply of 80,000 to 100,000 gallons per day was pumped into the stand-pipe, which was believed to be sufficient to prevent freezing on the water sur-

face. However, pumping was not in progress at the time of the failure.

The stand-pipe was constructed of "best quality" steel plates varying in thickness from 13-16 to 5-16 in. It was anchored to a substantial foundation by means of eight pairs of 2-in. bolts attached to plate brackets which reached to the top of the second course of plates. The 10-in. inlet pipe was located on the south side. Having been completed in July, 1886, six winters, more or less severe in character, had been passed through without the development of visible signs of weakness.

After the failure, the foundation and the bed-plate, with a portion of the three lower courses and the attached anchorage, as is rather dimly shown in the view, Fig. 12, were found undisturbed. The remainder of the stand-pipe separated into two portions, as shown in Fig. 12, a lower section of 50 ft. being carried 100 ft. northward, and the upper 85 ft. falling to the southward after first striking the undisturbed fragment of the lower plates. The lower section was split in a nearly vertical line from end to end upon what had been the south side of the stand-pipe, and the lower plates of the longer section were torn and bent by the force of the fall. Wherever brackets were torn away the anchor bolts were sheared off and the inlet pipe with its connections, weighing a half ton, was projected 100 ft. southward, partly demolishing a building.

As to the method and cause of the failure, nothing definite was agreed upon at the time, except that the existence of the ice in the stand-pipe had, in some unknown manner, led to its destruction. However, a careful study of all available facts and a comparison with previous accidents occurring under similar conditions suggest the following explanations:

During the formation of the ice walls the thickness was doubtless greater upon the north than

FIG. 12. VIEW OF COLLAPSED STAND-PIPE AT MARYVILLE, MO., LOOKING SOUTHWEST.

upon the south side of the stand-pipe, and this difference in thickness was probably materially increased during the several days of higher temperature which preceded the accident. Moreover, during the latter period the influx of freshly pumped water must have melted the ice for some distance above the base, and it is not improbable that the entire body of ice had been thawed loose from the metal shell through the influence of the solar heat, so that with the stand-pipe nearly or quite full, the mass of ice would be buoyed up against or perhaps slightly above the top stiffening angle. With these conditions existing on the evening preceding the failure, the small consumption of water during the night might easily have permitted the ice-tube to freeze fast in the above described position with the excessive fall in temperature. The melting loose under the reversed conditions of the following morning was a natural consequence, and, had the stand-pipe been full or nearly so, no signs of it would have been revealed. However, if the enormous energy stored in the suspended mass of ice (weighing probably not far from 1,000,000 lbs.) be considered in connection with the height of the water at the time of the accident (about 35 ft. below the top), the strains due to the fall above described would seem amply severe to cause the destruction of the stand-pipe. The initial rupture upon the south side might have been due either to the decreased thickness of the ice or to the blowing out of the inlet pipe connection.

This accident strikingly develops the fact that no positive assurance of immunity from ice accidents exists in the mere survival of any number of severe winters, but that the real danger occurs with the succession of extreme conditions about as above described, in connection with a stand-pipe partly empty at the critical moment.

(Since writing the above discussion of cause, careful consideration has been given to the excess in the rate of expansion of ice over that of steel, but

a more thorough inquiry into the local temperature records at and immediately preceding the time of the Maryville accident fails to disclose a range of temperature sufficient to warrant the acceptance of the heat expansion theory in this case. The additional facts thus collected are in full accord with the theory of falling ice as above advanced.

The investigation above referred to has developed some interesting points concerning the possible strains in the inclosing metal shell due to the expansion of the ice tube. These points will be given in the final discussion in connection with a brief summary of the several ways in which ice may be a source of danger to stand-pipes.)

References.—Maryville "Democrat," Feb. 28, 1893. Engineering News, Vol. XXIX., pp. 217, 294 (March 9, 30, 1893). Engineering Record, Vol. XXVII., p. 353 (April 1, 1893). Correspondence with the superintendent of the Maryville Water Co. (1893). Correspondence in 1894 with: The Chief of the Weather Bureau, Washington. D. C.; local observers at Clarinda, Ia., and at Columbia, Carrollton, Gallatin, Bethany, Conception and Pickering, Mo. (the last two being within a few miles of Maryville).

East Providence, R. I., Sept. 7, 1893.

The 40 × 120-ft. steel stand-pipe at East Providence, R. I., collapsed in the upper 35 ft. of its height during a severe gale about 7:00 p. m., Sept, 7, 1893, bending as shown by Fig. 13. As planned its height was to be 125 ft., but at the time of the accident the topmost course of plates with its stiffening angle was lacking. On Aug. 29, about a week preceding the accident, a severe wind storm struck the stand-pipe before the 24th course of plates was entirely completed, during which the top of the structure swayed violently in and out, and the empty stand-pipe was lifted ¾ in. or more from the foundation on the windward side. However, upon pumping it full of water no damage was observed and it was again emptied, in which condition the collapse took place as above mentioned during the most severe portion of the later storm, which resembled a cyclone. The excellent quality

of the material and workmanship was strikingly displayed when, upon the day following the accident, the stand-pipe was again pumped full and the indented portion was sprung into shape. A

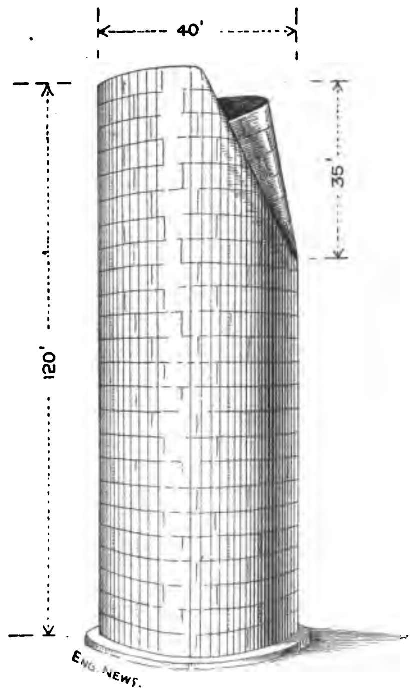

FIG 13 VIEW OF INDENTED STAND-PIPE, EAST PROVIDENCE, R. I., SEPT. 7, 1893.

single leak was found at the lower extremity of the bent plates, being due to a few strained rivets which were replaced, leaving the structure apparently "as good as new."

The unusually large diameter of this stand-pipe,

considering its height, makes its general construction, as shown by the specifications, particularly interesting.

The finished stand-pipe was to have 25 courses of plates, each 5 ft. in height. The thicknesses were to be as follows:

Course.	Thickness, inches.	Course.	Thickness, inches.
1	1 9-32	9	¾
2	1 3-16	10	11-16
3	1 5-32	11	⅝
4	1 1-16	12	9-16
5	1	13 and 14	½
6	15-16	15 and 16	7-16
7	⅞	17 to 20 inclusive	⅜
8	13-16	21 to 25 inclusive	5-16

The bed-plate was ¾ in. thick and 41¼ ft. in diameter, formed of radial strips. The 1 9-32-in. bottom course was secured to the bed-plate by a 6 x 6-in. angle, double riveted with 1-in. rivets spaced 2¾ ins. between rivets and 2¼ ins. between rows. Triple riveting with 1⅛-in. rivets and 8-in. laps was used in the first five horizontal and vertical seams; double riveting was used in the next ten horizontal and in the remaining vertical seams; and the last five horizontal seams were single riveted. The stand-pipe was erected by using inside staging.

The record from the self registering anemometer at Providence, about the time of the accident, indicates a maximum velocity of close to 38 miles per hour, and the extreme velocity recorded elsewhere during the same storm was somewhat above 40 miles per hour; but it is probable that the actual ultimate velocity during the most violent portion of the storm reached a considerably higher figure than indicated by the records above quoted. During the severe wind storm several days preceding the collapse, the estimated velocity of the wind when the stand-pipe was slightly lifted on the windward side was 60 miles per hour, which may with reason be assumed as the probable extreme velocity during the later storm. It is, however, important to observe that the collapse was perhaps directly due

less to the actual maximum force of the storm than to the coincidence of successive gusts of wind with the vibrations of the sides of the empty tank.

References.—Engineering News, Vol. XXX., pp. 205, 237 (Sept. 14, 21, 1893). Engineering Record, Vol. XXVIII., p. 298 (Oct. 7, 1893). Correspondence with the city engineer, Providence, R. I., and with the chief of the Weather Bureau (1893). Engineering News, Vol. XXXI., p. 76 (Jan. 25, 1894). Engineering Record, Vol. XXIX., p. 135 (Jan. 27, 1894).

East Providence, R. I., Jan. 19, 1894

The 40 x 125-ft. steel stand-pipe at East Providence, whose collapse during a severe wind storm on Sept. 7, 1893, was described just above, burst at 7:50 p. m. on Jan. 19, 1894, at which time it is said to have contained less than 100 ft. of water.

As stated in the foregoing description of the first accident, the damage resulting from the collapse was supposed to have been slight, being confined apparently to the wrinkles in the plates at the lower limit of the collapsed portion. After considerable effort by the contractor, the wrinkles were so much reduced as to be scarcely perceptible when the water level was above them; but upon lowering the water to the 85-ft. level the dent in the plates became so distinct that the local authorities would not accept the structure from the contractor, and finally it became necessary to suspend operations on account of the cold weather. Previous to the latter, however, the sub-contractor for the roof and balcony had proceeded with and completed his work, although the floating staging, consisting of timber and barrels, which had been used by him in erecting the roof, had not been removed from the stand-pipe at the time of its final failure. For some time prior to Jan. 14, about one week previous to the failure, there had been no communication with the mains, but on that date the valve was opened by the contractor after cutting the ice on the surface of the water loose from the walls of the stand-pipe. This communication with the mains was not disturbed up to the time of the failure, when, as

already stated, the water level is said to have been less than 100 ft. above the base.

The ruins of the wrecked stand-pipe are thus described by Mr. G. H. Leland, Assistant to the Designing and Consulting Engineer:

From general appearances it seems the pipe first burst at a point 55 ft. above the bottom on the southwest side. The first ten bottom courses on the same side were rent asunder and were unrolled and carried a distance of 150 ft. to the northeast with the lowest course farthest away from the foundation and outside uppermost. One large section of the bottom course was hurled over a pile of earth, some 10 or 12 ft. high, without even scratching the earth.

The upper 75 ft. appear to have dropped perpendicularly just south of the foundation and then toppled over to the south. The roof lies all within the pipe, with the peak lying diagonally down, excepting one dormer window, which was hurled to one side. * * * The foundation of the pipe, which was laid up in Portland cement, remains intact. The bottom of the stand-pipe remains on the foundation, but with the edges torn and twisted. * * * The heavy steel plates that composed the lower courses are bent, twisted and torn into innumerable shapes and sizes, but the triple-riveted joints remain firm and solid; in one or two cases, however, the double-riveted joints pulled apart instead of tearing the plates. * * * The fractures and flexures of the steel plates show an excellent quality of material.

The sketch plan, Fig. 14, was prepared at the ruins by Prof. J. M. Porter, of Lafayette College, Easton, Pa. It is slightly in error in that the length of the piece marked T should be 125 ft. instead of 95 ft. on the edge nearest the foundation, although the more distant edge had the length shown in the plan. Prof. Porter agrees with Mr. Leland in locating the point of initial rupture on the southwest side of the stand-pipe, a conclusion which seems to be confirmed by an examination of the plan of the ruins given in Fig 14, for it is seen that the major portion of the ruptured lower section was projected to the northeast and that the upper portion of the stand-pipe fell to the southward.

However, the above-mentioned authorities do not agree as to the height above the base of the stand-pipe at which the first break occurred, for, as

above quoted, Mr. Leland is of the opinion that the first rupture took place at a point about 55 ft. above the base, in support of which he refers to

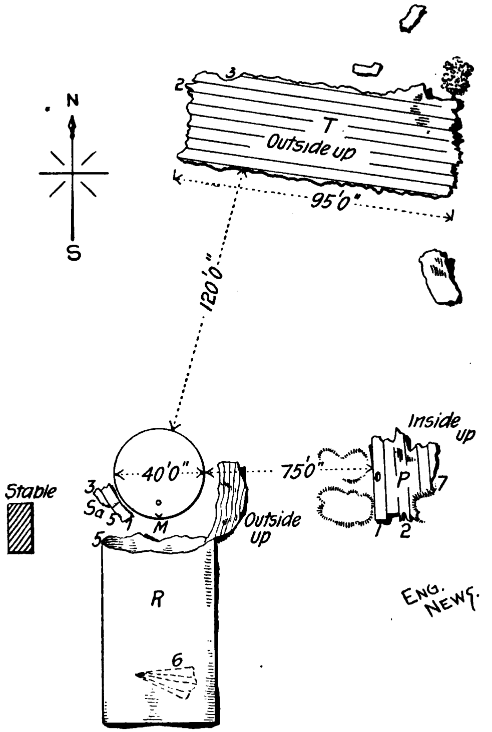

FIG. 14. SKETCH PLAN OF WRECKED STAND-PIPE AT EAST PROVIDENCE, R. I.

the photographic view, Fig. 15, of Piece T, and calls particular attention to Point A, which was originally located in the 11th course on the south-west side, as follows:

This place presents the appearance of having re-

FIG. 15. PORTIONS OF WRECKED STAND-PIPE, EAST PROVIDENCE, R. I.

ceived a terrific concussion of some kind from the inside. The fractures of the plates at this point radiate in all directions, with the edges rolled outward.

The statement by Prof. Porter, accompanying his sketch plan, was as follows:

The initial rupture evidently occurred in the lower 45 ft., about 18 ft. southwest of the manhole, near S, Fig. 14, probably in the second ring. These lower rings, being torn free from the top rings and the ⅞-in. angle connecting them to the bottom, were straightened out and carried away with their thicker courses in advance. The portion P, striking a small rise in the ground, separated from T, and was found inside up 75 ft. to the west of the foundation, with its edge marked 7 buried in the ground. This fragment, P, composed a portion of the five bottom rings, and contains the manhole originally at M. The Portion T is nearly nine rings wide, and approximately 95 ft. long. It was found about 120 ft. north of the base, outside up, with its thicker courses to the north, as shown in the view, Fig. 16. This portion is by far the largest of the fragments. Farther north were found smaller fragments of the bottom ring. Portions T, P, S, together with other small and shattered fragments, once formed about the nine lower rings, or 45 ft. Points 2 of P and T were found to coincide exactly. The small fragment, S, found near the masonry, gave indications of having simply fallen over. It comprised a portion of the first and second rings. Points 1 of S and P fit perfectly, as do Points 3 of S and T. Point 5 of S gave conclusive evidence of having received a hard blow from 5 of R, Fig. 14, but not until S had fallen past a horizontal position. As most of the fractured rings were thrown to the north by the reaction of the water, it was but natural that the remaining top rings should fall to the south; such was the case, as shown by the diagram, Portion R. The conical roof, made of iron, was found badly bent, but without many fractures, inside the pipe at 6 of R. The top of the north end of R was opened up and laid outside up, as shown on the diagram and in Fig. 16.

The following extract from a statement by Mr. S. M. Gray, M. Am. Soc. C. E., designer of the East Providence stand-pipe, is of much interest, in that it bears upon the quality of the design and material:

The stand-pipe was designed to have a factor of safety of very nearly six for the lower rings or courses, five for the middle, and four for the upper rings. No ring had a factor of safety less than four. In short, the stand-pipe was built to stand the strain of static pressure from four to six times greater than it would be normally subjected to. . . . The specifications call for American rolled steel which would stand

FIG. 16. GENERAL VIEW OF EAST PROVIDENCE STAND-PIPE FAILURE.

60,000 lbs. tensile strain to the sq. in. The metal was very uniform in strength, as was shown by tests made from samples taken from some forty sheets selected at random. The least tensile strength of any specimen was 59,540 lbs. to the sq. in., the greatest being 64,880, the average being upward of 62,000 lbs. to the sq. in. . . . There is no evidence to show that the accident was due to poor material or inferior workmanship. On the contrary, both material and workmanship appear to have been excellent.

It has been charged that the cement bed under the bottom of the tank was deficient about the

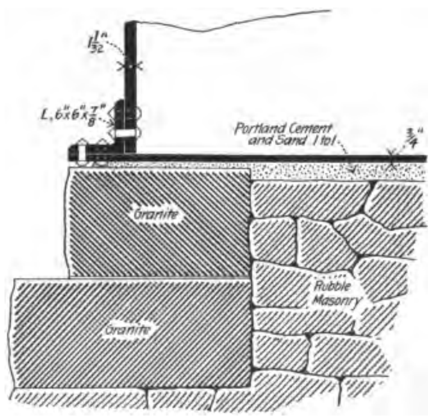

FIG. 17. SECTION SHOWING BOTTOM OF EAST PROVIDENCE STAND-PIPE AND TOP OF FOUNDATION.

edges, but Mr. Leland shows in Fig. 17 the details of the top of the foundation, and states that the bedplate had a firm bearing throughout, it having been intended to point up around the base after the stand-pipe had been filled and had found its bearing in the bed of dry cement and sand.

In addition to the above, the following statement from the same authority is of much interest, in that it suggests the most plausible theory for the failure of the stand-pipe:

Large blocks of ice lie strewn around in various

directions, varying in thickness from 3 to 18 ins. Several large rectangular blocks of ice 2 to 3 ft. square and 3 ins. in thickness were found with the imprint of the rivet heads, showing that the ice was formed more or less to the inside of the pipe, to just what extent it is impossible to state.

From information obtained through another source, it seems that rattling sounds were heard within the stand-pipe upon the day preceding the accident. but no opinions as to the probable cause, either of the sounds or the failure itself, have been advanced. It therefore becomes necessary to carefully consider all facts bearing upon that point; and inasmuch as the quality of plate-metal as indicated by the results of both accidents, seems to have been of unusual excellence, any reasonable theory must account for the existence of extraordinarily severe conditions.

At first thought it would appear that the failure was in some manner the result of the earlier accident, but it is observed that the 35-ft. portion at the top, which had previously collapsed, was entirely included within the 75-ft. section which toppled to the southward after the lower ten courses had burst. It is, nevertheless, not impossible that the plate-metal, even though exceptionally superior in quality, might have been damaged or overstrained at some point below the collapsed portion during the period of excessive vibration which accompanied and preceded the first accident. However, admitting the existence of such defects, it is difficult, if indeed possible, to explain how such a cause, acting singly, could have produced the disastrous results; although there is reason to conclude that such defects, if any existed, may have had an important auxiliary influence when acting in connection with other elements.

The wide variation in the thickness of the ice found in the ruins, indicates that the ice tube which formed, during the period of cold weather while communication with the mains was cut off, was eccentric in shape, having a thickness of 18 ins. on

the northern side and of only 3 ins. on the southern or southwestern side, where the action of the sun was greatest. (In proof of the latter idea, reference is made to Eng. News, Vol. XXVII., p. 347 (April 9, 1892), which describes the construction of a 30 × 100-ft. stand-pipe by the floating derrick system in a western city. The stand-pipe proper had been completed and it was intended to rivet on the stairway brackets by gradually lowering the float, "but it was found that a ring of ice had formed inside the stand-pipe, 18 ins. thick on the north side, but only 2 ins. thick on the south side where it was exposed to the sun.") The tube of ice in the East Providence stand-pipe doubtless formed against the interior cylindrical surface up to the stationary level of the water and it would seem that the connection of the ice with the bed-plate was watertight. Assuming such to have been the case and that the action of the sun upon the south or southwest side of the stand-pipe had formed a film or pocket of water between the metal and ice shells upon that side, it is only necessary to have had a freezing temperature in order to subject the stand-pipe to strains probably more severe than may be otherwise possible, unless, perhaps, it be those which are produced by the fall of a large body of ice through a considerable distance. Inasmuch as the latter was impossible under the existing circumstances the former is here advanced as the most probable explanation of the failure. It may properly be added that according to this theory the pocket, and consequently the initial rupture, would naturally occur on the south or southwest side of the stand-pipe, and that rupture might take place at almost any point in the lower nine-tenths of the height of the ice tube, the strain required to produce rupture growing less, of course, with the decrease in the thickness of the plates. Thus, it will be seen that if the initial rupture took place at a point 55 ft. above the base as above suggested, the pocket of confined but unfrozen water probably ex-

isted there, and the failure originated in a plate having a thickness of ⅝ in. It is, furthermore, of importance to observe that the formation of such pockets is probable only when the ice tube extends to a tight connection with the bed-plate, which latter condition may rarely if ever be found to exist except when the stage of the water remains constant for some time during freezing weather, such for instance as was the case of the Asheville stand-pipe. In proof of the fact that the force generated in the manner above indicated would be sufficient to cause plate fracture, rèference may be made to the well-known "bomb-shell" experiments or to the various evidences in nature of the powerful action of frost.

Since writing the above discussion, extracts from the local meteorological record have been obtained through the courtesy of Mr. J. Herbert Shedd, City Engineer of Providence, R. I. Although the temperature, cloud and wind records for Jan. 19, and for a day or two previous, are not distinctly those above assumed, it is not necessary, for that reason alone, to abandon the theory above advanced; for it seems entirely within reason that with steel having the excellent qualities previously exhibited by the plates in the upper portion of the stand-pipe, it would be possible that the expansive force might have been acting intermittently, or perhaps continuously, through a considerable period of time, and that on the evening of Jan. 19, when the temperature was at, or slightly below, freezing, the contractive tendency of the already strained plates, acting in conjunction with the above-mentioned expansive force of the confined water pocket, caused the initial rupture on the southwest side.

While Point A, shown in Fig. 15, and which, it should have been stated, is at the southeast corner of the large fragment, T, in Fig. 14, presents striking proof of the action of a concentrated force, such as that above accounted for, it seems

probable that rupture may have taken place almost simultaneously along the element of the cylinder, and it is undoubtedly true that the interval of time within which the lines of rupture passed through the demolished lower portion must have been exceedingly small.

References.—Engineering News, Vol. XXXI., pp. 76, 112, 160, 180, 202 (Jan. 25, Feb. 8 and 22, March 1 and 8, 1894). Engineering Record, Vol. XXIX., p. 135 (Jan. 27, 1894). Correspondence with the city engineer, Providence, R. I. (1894).

Peoria, Ill., March 30, 1894.

The 25 × 120-ft. steel and wrought iron standpipe, located on the "west bluff" at Peoria, Ill., burst and fell at 10:20 a. m., March 30, 1894. One person, a boy, was crushed under a falling plate, and 15 other persons were more or less injured; the damage to surrounding property was extensive.

A very complete survey of the premises was made immediately after the failure occurred, under the direction of Mr. J. A. Harman, City Engineer of Peoria. The inset sheet here given, containing the survey sheet, Fig. 18, and the photographic views, Figs. 19 to 25, originally appeared in Engineering News of April 26, 1894, in connection with an admirable report upon the failure by Mr. Harman. This report being of much interest, and also the most complete of the kind yet made, it is here quoted in full*:

Previous to the failure, small leaks at various joints in the lower six or eight courses had been noticed, and on the morning of the failure workmen were sent to repair these leaks. The stand-pipe had about 105 ft. depth of water at the time, and was connected to the supply system by a 16-in. main through its bottom, and was in service at the time of the failure. The day was bright and clear, and a strong breeze

* A valuable illustrated report on this accident by Mr. Dabney H. Maury, Jr., Superintendent of the Peoria Water Co., is given in Appendix II. Mr. Maury's report had not been made public, for reasons stated in the Appendix, when Professor Pence prepared his account of the Peoria failure.—Publishers.

was blowing from the west. A boilermaker was calking a leaky joint at the top of the first or bottom course on the north side of the stand-pipe when the failure occurred.

From a careful study of the wreck, on the ground, and of the plan and photographs, the following conclusions have been reached:

The first rupture was near the point which was being calked, at the top of the first course at the north side of the stand-pipe, near a vertical joint in the second course, which is located at the northwest corner of the east course of the piece designated as No. 4 on the plan shown by Fig. 18. The fracture went nearly vertically through the bottom eleven courses. From the point of initial rupture the fracture coursed downward through the first course and reached the bottom toward the west, about 8 ft. from the north point. The bottom three courses and part of the fourth, Piece No. 24, were swung around to the west and torn off from the body of the tank a little east of the south point, and were thrown a little west of the south, striking and completely wrecking a cottage which was 78 ft. distant from the stand-pipe. In so doing it pulled out a number of the anchor bolts on the west side. The breaking and dislodging of the coping stone clearly show that Piece No. 24 ripped off and swung around to the south. Its position on the ground also gives that conclusion. Piece No. 24 is 42 ft. long, and contains over half of the bottom three courses of the circumference of the stand-pipe, the remaining portion of these courses being in sheets, Pieces Nos. 4, 17 and 26, and smaller detached fragments.

The bottom of the stand-pipe remains in position, with the first course showing a ragged edge, broken off at some places along the top of the base angles, at others running a foot or more above, and at still others tearing the rivets out of the base angles.

After the bottom three courses had been torn out on all except the southeast side, the stand-pipe fell toward the north, the northeast corner of Piece No. 3, Fig. 25 on the inset sheet, and the west corner of Piece No. 12, striking on the bottom, the former cutting the two easterly gashes, the latter the two westerly, leaving the 11 $\times$ 16-in. piece of plate stuck fast in the bottom. These points of Pieces Nos. 3 and 12 were directly over the cuts in the bottom, and No. 3 is badly cracked and battered at its northeast corner, while the west corner of No. 12 is bent and broken off, a portion of it being irregular and bent fragments, marked Nos. 29 and 30, lying under Piece No. 12.

After Pieces Nos. 3 and 12 struck the foundation, No. 3 apparently broke loose from the body of the stand-pipe, leaving a great gap, having taken out a large portion of Courses 4, 5, 6 and 7 on the northeast. The tendency of the tank was then to fall nearly east, which was augmented by the strong breeze from the west, and this, together with the holding of Piece No. 24, and the first anchor shown on the plan east of the south point of the foundation, gave it a rotary motion

through an arc of approximately 100°. Almost simultaneously Sheets Nos. 12 and 26 were detached from the upper portion, making, in fact, a second rupture, which included Courses 4, 5 and 6, and that portion of Courses 1, 2 and 3 shown in Piece No. 26, the latter piece being shown in the view, Fig. 23.

After Piece No. 3 had blown out, the stand-pipe struck again on its end, as is shown by the badly battered condition at the southwest corner of Piece No. 2, Figs. 19, 20 and 21.

The peculiar position of Piece No. 26, the upper courses being inside up and the lower courses with the manhole being outside up, with a sharp bend at the south, would indicate that the fracture here was earliest in the upper or fifth course on the southeast side; and also that before that portion was broken loose at the base, the top had bent down, or that the small portion then remaining intact bent inward when the tank settled, and when broken and carried out at the bottom by water the weight of the sheet and pressure of the water completed the bending.

The large pieces of the bottom courses being, almost without exception, pointed away from the stand-pipe and outside up, indicate that, as a rule, the earliest breaks horizontally were in the bottom course.

When the tank fell, nearly all of the steel sheets were cracked at the south side, where the tank is flattened, but the top six courses of ¼-in. wrought iron and the next two courses of steel are not thus cracked.

The fractures of all the steel plates, from the thickest to the thinnest, had practically the same appearance, many of these being comparatively very smooth or crystalline, while the breaks in the wrought iron sheets at the top, and the angles at top and bottom, are quite fibrous.

The photographs from which the views were reproduced were made by Mr. W. C. Parmley, Assistant City Engineer, and I also wish to acknowledge the valuable assistance and suggestions of Mr. W. C. Evans, of Harman & Evans, and Mr. A. D. Thompson, Assistant City Engineer, who conducted the surveys and prepared the plan.

The following additional information relative to the views on the inset accompanied Mr. Harman's report:

In Fig. 20 the point of view was 20 ft. west of the northwest corner of the main body of Piece No. 2 The coil of steel shown in Fig. 21 is inside of Piece No. 2, and was rolled up from the under side. In Fig. 22 the cracks are on the south side of the pipe as it lies upon the ground. Similar cracks occur in all the courses up to and including the sixteenth from the bottom. The eight upper courses did not break. A 2-ft. rule is shown in the foreground of this view. The boy was killed under the farther edge of the plate shown in Fig. 25.

FIG. 26. WRECKED STAND-PIPE AT PEORIA, ILL., LOOKING NORTHEAST.

The view, Fig. 26, looking northeast, shows the base and foundation of the stand-pipe and the location of the inlet. The child in the foreground was rescued uninjured from the cottage, which was wrecked by the large piece, No. 24. The portion of the pipe shown partially straightened out at the left of this view is the seventh course. Fig. 27 shows the stand-pipe above the lower and shattered courses, looking a little south of east, with the foundations in the distance. The blocking was used to raise the wreck in the search for bodies.

The following remarks concerning the Peoria stand-pipe and its failure were communicated to Engineering News of May 10, 1894, by Mr. W. C. Parmley, Assistant City Engineer:

(1) On Jan. 5, 1894, by observations with a transit instrument, I found that the tower leaned some 3 or 4 ins. toward the northeast. People living in the neighborhood testify that when filled the water always ran over on the northeast side.

(2) The wind from the southwest, according to my estimate at the time, was blowing about 30 miles an hour. Possibly this is a high estimate, but I feel certain the velocity was above 20 miles per hour. The temperature in the shade was about 58°, and in the sun about 66° F., the sun being dimmed by thin, hazy clouds.

(3) The failure occurred immediately after the pipe had been subjected to vibrations caused by workmen calking joints.

(4) In all cases the failure of the steel was short and brittle. In many places it cracked in a manner reminding one of broken plate glass. The fractures were always crystalline, usually of rather fine structure, in some cases resembling that of drill steel. Numerous checks and cracks radiate from the rivet-holes, showing that the metal was too brittle to be punched without injury.

(5) The fractures were as often through the solid plate as along the riveted seams, and rivets were sheared in only a few instances. . ,

The ice which formed in the stand-pipe during the winter season preceding the failure must have melted entirely during the period of warm weather which prevailed early in the month of March, for none was found in the ruins. It is true, however, that the week preceding the fail

ure had been remarkable for its fluctuations of temperature. The local offical record shows that a minimum temperature of 13° F. had been reached within a period of five days, and that a temperature of 18° F. was observed on the day before the failure. In more exposed locations in that vicinity temperatures below 10° F. were observed during two or three nights in succession,

FIG. 27. FLATTENED PORTION OF PEORIA STAND-PIPE.

and it is stated that ice to the thickness of 1½ ins. formed during the night of March 24.

Mr. Chester B. Davis, the engineer who designed the structure, after making a thorough investigation of the ruins, reached the following conclusion:

A careful study of relative positions of the pieces, as they now lie, of the condition and position of the holding-down bolts, the effects of the water and other facts

bearing upon it, shows that the rupture began on the north side of the tower, at or near a seam between the first and second courses, and its joint between two second course plates, and from there it tore upward to the right and to the left.

Mr. D. H. Maury, Jr., Superintendent of the Peoria Water Co., states that there had been a slight leak or discoloration about 35 ft. from the base on the northwest side of the stand-pipe, and that when the men were sent to repair the leaks on the morning of the disaster, it was found sufficient to paint over the spot referred to. This joint and the plates around it were found intact and unbroken in the ruins, so that it was known that the fault was not at that point.

The thicknesses and kinds of plates are given in Fig. 18, and the following is quoted from the specifications as communicated by their author to Engineering News of April 5, 1894:

The metal of the plates must be of a soft, homogeneous steel, unless otherwise specified, possessing a maximum tensile strength of 66,000 lbs. and minimum tensile strength of 55,000 lbs. per sq. in., and be officially and legally stamped; must be smooth, truly and evenly rolled, and uniform in size, and sufficiently ductile to admit of rolling while cold around a radius of 20 ins., without developing flaws, cracks, splits, or any other features which would render them unfit for the work in the opinion of the engineer. The plates will be inspected by the engineer, upon notification, before being put into the pipe and before painting, and all improper plates will be rejected.

Where iron plates are specified the iron must be best quality tank iron, having a tensile strength of 48,000 lbs. per sq. in. Test pieces of the plate will be made and broken by the contractor in the presence of the engineer when he may desire, and at no extra expense to the purchaser. . . . Burden's "best-best" rivets must be used for the whole work. . . . Lay all holes out carefully and accurately and punch with a center punch, sharp and in perfect order, from the surface to be in contact and so that the bevel of the hole may be away from the surface in contact.

Plates showing any indication of hardness or brittleness may be annealed after punching, or rejected, at the option of the engineer. Plates having ragged holes or holes so much out of place as to require the use of the drift-pin will be rejected. All plates must be planed to a slight bevel in a machine, and be carefully calked with a round-nosed tool and made perfectly tight. Lay all the work out so that each joint

will come halfway between those of the next course. Where three plates join, the overlap is to be neatly scarfed down while hot. Heat rivets uniformly and carefully, and never set one when colder than red-hot. The riveting must be done in a neat and workmanlike manner. . . . After inspection, which will be at the shop, each sheet must be cleaned and painted with, or dipped into a bath of, hot asphaltum, and before being placed in the stand-pipe. There must be no paint on surface in contact. After testing, the work will be given two coats asphaltum or lead in oil, to suit the engineer. . . . The stand-pipe will be tested before receiving the final coats of asphaltum, by being filled with water and by being allowed to remain full for such time as the engineer may deem necessary to satisfy himself that the work is water-tight.

Mr. Eugene Carroll had direct charge of the construction of the stand-pipe. Prof. J. B. Johnson, of St. Louis, Mo., acted as consulting engineer for the city of Peoria when the water-works were approved in June, 1892, although the stand-pipes having then been in service for more than two years, it was, of course, impossible to judge of the quality of the structural material.

A strip of steel cut for the coroner from a fragment of the first course attached to the base angle on the west side of the stand-pipe was sent to Robert W. Hunt & Co., of Chicago, which firm, under date of April 12, 1894, submitted the results of physical and chemical tests of the sample, as given in the accompanying table.

For the purpose of applying a cold bend and punching test to the metal, Prof. J. B. Johnson on April 28, 1894, requested through the editor of the Peoria "Journal" that a sample from a fractured lower ring plate be sent to him, and as a matter of convenience the piece was cut out adjoining the vertical strip removed by the coroner, the tests of which are given above. Professor Johnson thus comments upon the test made by him:

I punched it and bent it cold, both in the body of the specimen and also across the punched hole. While this metal is not the best the market affords, it is not so inferior as to seem to explain the cause of the failure.

Physical and Chemical Tests of Steel from the Wrecked Peoria Stand-Pipe.

Physical test of steel.

Original dimensions, ins.	2.00 × 0.760
Dimensions after fracture, ins.	1.695 × 0.629
Original area, sq. ins.	1.52
Fractured area, sq. ins.	1.0571
Elastic limit, lbs., actual	57,970
Maximum load, lbs., actual	92,960
Elongation in 8 ins., ins.	1.89
Elastic limit per sq. in., lbs.	38,138
Maximum load per sq. in., lbs.	61,150
Per cent. elongation in 8 ins.	23.6
Per cent. reduction of area	29.8
Character of fracture	Laminated

Chemical test of steel.

Drillings taken from "side" of piece:	Per cent.
Carbon by combustion	0.124
Silicon	0.011
Sulphur	0.046
Phosphorus	0.133
Manganese	0.42
Drillings taken from "end" of piece:	
Carbon by combustion	0.136
Silicon	0.003
Sulphur	0.049
Phosphorus	0.130
Manganese	0.42

In reference to the coroner's tests of the metal, he adds:

Both the physical and chemical tests are also fairly satisfactory, so that none of these tests are sufficient to explain the accident.

An inspection of the bent sample above referred to (made by the writer through the courtesy of the editor of the above-named local journal) shows that the strip was ¾ × 2× 12 ins. It had bent through an angle of about 144°, on a curve having a radius about equal to the thickness of the sample, before the exterior fibers parted, and apparently the bend across the ¾-in. hole, punched near one end, had reached an angle of about 8° before fracture began at the edge of the hole.

While it was, of course, entirely just to test samples from an undisturbed plate, it should be remarked that the qualities displayed by the samples taken from the west side of the structure are

not conclusive as to those which might have been shown by the metal near the north point, where, as already stated, it seems that initial rupture took place. The writer has seen the result of a careful analysis of steel borings taken from an exceptionally brittle and crystalline fragment of small size from the first and second courses, and found in the western portion of the ruins at a point indicating that its original position had been in the northwest quadrant of the stand-pipe. This analysis showed phosphorus 0.162%, the other elements being about as found in the coroner's test above quoted. No physical test of this piece was made because it broke short off in the attempt to cut out a sample strip.

The determination of the point of initial rupture, and of the action of the several parts of the fractured metal shell, forms a very interesting problem, and reliable conclusions upon those points may often require much investigation and the closest study. However, such matters should not be permitted to obscure the one important question of "cause of failure," and their consideration should be given prominence only for the distinct purpose of throwing light upon the more essential point. The conclusion that the initial rupture took place near the north point is doubtless the correct one, since it was reached by both of the authorities above quoted after several days' study of the ruins. This opinion, it will be observed, is confirmed by the fact that the largest fragment of the lower portion of the stand-pipe, piece No. 24, Fig. 18, was carried to the southward by the reaction of the escaping water. The general scarcity of fragments to the due north, and the presence there of the small piece, No. 11, which was projected a distance of 201 ft. in a direction just opposite that of piece No. 24, also indicate the truth of the above conclusion. Study of the ruins of various other stand-pipes would indicate that the upper

portion should have fallen in the approximate direction of the point of first failure. That this did not take place at Peoria would seem to have been due to the combined influence of the above-quoted fact that the stand-pipe leaned appreciably to the northeast, and also because the wind was blowing from the southwest at the moment of failure. It is worthy of remark, that the striking manner in which the lower portion of the stand-pipe went to pieces is in full accord with the brittle character of the metal, as shown by the fractures themselves.

The coroner's jury found that the failure "was occasioned by the use of inferior material in construction."

The quality of the steel plate, as shown by the factures themselves, was unquestionably of an undesirable kind, but the physical properties, as shown by the test above tabulated, were not those of distinctly objectionable steel, except that many engineers would desire a greater reduction of area. It is seen, however, that the chemical tests unequivocally brand the Peoria steel "high phosphorus," and it has been found that such steel may sometimes give favorable machine tests under gradually applied loads, while under the action of shocks or vibratory stresses sudden failure is probable. Furthermore, noting the difference in phosphorus (0.03%), shown by two samples taken from different points in the stand-pipe, the inference seems warranted that physical qualities of a widely varying character might have been revealed by a rigid and systematic series of structural tests. Whether the specified tests were made during the manufacture of the stand-pipe has not been stated, but an inspection of the surprisingly lax requirements of a cold bending test compels the conclusion that its enforcement was a matter of little importance, for without doubt even the most brittle of the plates in the Peoria

stand-pipe could have bent cold about a cylinder 40 ins. in diameter (20 ins. radius) without sign of fracture. The following comment upon the specifications, by Professor Johnson, to whom reference in another connection has been made above, is quoted from a communication under date of April 24, which appeared in the columns of a local journal on April 26, 1894:

> The specifications for this stand-pipe were not sufficient to guarantee the right kind of material, even if they had been followed up by a complete and careful inspection.

The marked prevalence in the ruins of cracks radiating from rivet-holes, illustrates the almost certain damage which results to such steel in the process of punching the thicker plates; and in seeking a cause for the failure, it does not seem improbable that a few such lines of incipient fracture may have been extended during the sudden and excessive fall of temperature within a week preceding the failure, by the enormous expansive force accompanying the freezing of water which had leaked into imperfectly fitted rivet-holes. As to the sufficiency of such a force to bring about the result above suggested, there seems to be ample proof, and its effect would be at a maximum on the north side of the stand-pipe with the greatest exposure to cold winds. Whether a local weakness was produced in a manner above outlined or by other means, it is true that the initial rupture took place at or near the point on the north side of the stand-pipe, where calking was at the time, or a moment before had been, in progress; and it is generally believed that the failure was precipitated by the sharp vibrations produced in the metal shell by the calker's blows.

In conclusion, it should be stated that the details of the Peoria stand-pipe (see Engineering News, Vol. XXVIII., p. 26, July 14, 1892 inset) were uniformly of an excellent character, and that with

proper quality of metal in the plates, the structure would have been entirely safe.

The foregoing description of the Peoria failure was prepared in June, 1894. Owing to the fact that a 30 × 80-ft. stand-pipe, located in the residence district of the East Bluff, was built under the same specifications and at the same date as the wrecked West Bluff stand-pipe, the authorities of Peoria, through their engineer, Mr. J. A. Harman, engaged the Pittsburg Testing Laboratory to report upon the material and workmanship of both structures. The report of the experts was made public in September, and was fully abstracted in Engineering News, Vol. XXXII., pp. 266-7 (Oct. 4, 1894). Although no physical tests of the plates in the East Bluff stand-pipe could be made, the quality of the metal in the two structures was shown unmistakably to be identical. As a result of the unreserved criticism of the material and workmanship used in the construction, the East Bluff stand-pipe was removed during the latter part of 1894 by order of the Peoria city council. It is quite certain that no stand-pipe failure has hitherto attracted such general attention, and it is a significant fact that its influence has led to litigation elsewhere on account of alleged depreciation of values of real estate contiguous to stand-pipes.

References.—Engineering News, Vol. XXXI., pp. 283 and 286, 306, 339 and 346, 391 (April 5, 12, 26 and May 10, 1894). Engineering Record, Vol. XXIX., pp. 298, 314 (April 7, 14, 1894). Fire and Water, Vol. XV., p. 132 (April 7, 1894). Correspondence with the Editor of Peoria Journal and with the Superintendent of the Peoria Water Co. (1894). Personal inspection of the ruins (March 31, 1894).

Classification and General Discussion.

Table I. presents the subject of stand-pipe accidents and failures in a general manner by summarizing the principal points of the preceding record, and Tables II. to IX., inclusive, classify the general record under the several points of distinction, thus

ND FAILURES.

nd probable cause of failure.	Extent of damage.	
ned plates.	Total failure; burst.	1
lamaged plates.	Total failure; buckled and burst	2
inner pipe empty.	Partial failure; collapsed.—(Repaired).	3
ring fire. Damaged plates.	Partial failure; burst.—(Repaired).	4
r. Damaged plates.	Total failure; burst.	5
tive foundations under columns	Total failure of tank and frame.	6
ty; during erection. Deficient	Partial failure; overturned.—(Repaired).	7
empty. Thin plates (3-16-in.),	Partial failure; collapsed in empty portion.—(Repaired).	8
water. Poor design; defective	Total failure; burst.	9
test. Deficient anchorage; thin	Total failure; collapsed: overturned.	10
to test. Deficient top stiffness.	Slight damage; collapsed.—(Repaired).	11
pairs. Deficient anchorage and	Slight damage; collapsed; anchor bolt broke.—(Repaired).	12
. Overstrained hoop.	Total failure of tank and frame; burst.	13
ft. of water in tank; pumping.	Total failure of tank and brick tower.	14
etion; full of water. Defective	Total failure; burst.	15
ted and inner pier nearly so. Vitor.	Partial failure of tower; central pier overturned.	16
inside ladder; partially empty.	Slight damage; ladder broken down.—(Ladder removed).	17
r. Defective plates.	Total failure; burst.	18
aged plates; falling ice.	Slight damage.	19
rtially empty. Fall of ice; de-	Slight damage; plate bulged and cracked.—(Repaired).	20
mping. Damaged plate.	Total failure; burst.	21
r. Overstrained hoop.	Total failure of tank and frame.	22
e weather. Overstrained hoops.	Total failure of tank and frame.	23
en fall in temperature. Dam-	Total failure; burst.	24
d rise in temperature; inside top	Total failure; burst.	25
rection; top course lacking. De-	Slight damage; collapsed.—(Repaired).	26
. Ice.	Total failure; burst.	27
et of water; calking; wind. De-	Total failure; burst.	28

27, East Providence, R. I.

affording a ready means for studying the subject in its various phases.

It will be observed in Table II. that of the 28 cases included in the record, 17 were total failures, 5 failed partially, and in 6 of them only slight damage was sustained, making the number of total failures six greater than the combined number of less serious accidents. This excess is partly explained by considering other features of the classification, for which purpose the extent of damage sustained in each case is indicated in the subsequent tables. It is but just to say, however, that this relative excess of total failures may be due to the omission, from this record, of accidents in which the resulting damage was not serious; for, although, as was stated in the introduction, an extended search indicates that no accident of importance has been omitted, cases which were not serious enough to warrant general publicity at the time of their occurrence might easily have been overlooked.

A strict classification with reference to cause presents serious difficulties in a number of the accidents, making it necessary to take more or less license in the preparation of Table III., and inasmuch as the questions of cause and existing conditions are intimately related, the two items have been included in the one table. As might have been anticipated, Table III. reveals the fact that the most prolific source of accidents has been simple hydrostatic pressure or the combined effect of ice and water, there being ten instances of the former and nine of the latter, making ten more than the combined number due to other causes. Of the latter, six were due to wind pressure and three to defective masonry. It is also seen that cases of total failure are not confined to any particular cause, although 14 of the 17 total failures took place under the two heads first mentioned, only one occurring under wind pressure, and two being due to defective masonry.

TABLE II.

Classification of Stand-Pipe Accidents and Failures with Reference to Extent of Damage.

Total failures.

Cleveland,	Newport,	Wheatland,
Jersey City,	Franklin,	Asheville,
Cincinnati,	Seneca Falls,	Maryville,
Lexington,	Temple,	E. Providence,
Gravesend,	Defiance,	Peoria.
Kankakee,	Nappanee,	Total, 17,

Partial failures.

Sandusky,	Caldwell,	Thomasville.
Sandusky,	Victoria,	Total, 5.

Slight damage.

Asheville,	Defiance,	E. Providence.
Plattsmouth,	Stevens Point,	Total, 6.
Greencastle,		

TABLE III.

Classification of Stand-Pipe Accidents and Failures with Reference to Existing Conditions and Probable Cause.

Failure of metal caused by—		
Water.	Ice and water.	Wind.
Cleveland.....T	Jersey City...T	Caldwell.......P
Sandusky......P	Greencastle...D	Victoria........P
Sandusky......P	Defiance......D	Kankakee......T
Cincinnati.....T	Stevens Point.D	Asheville......D
Gravesend.....T	Defiance......T	Plattsmouth...D
Newport.......T	Wheatland....T	E. Providence..D
Seneca Falls..T	Asheville......T	
Temple........T	Maryville.....T	
Nappanee......T	E. Providence.T	
Peoria.........T		
Total 10	Total 9	Total 6

Failure of masonry caused by—	
Water.	During construction.
Lexington..............T	Thomasville...........P
Franklin...............T	
Total................ 2	Total................ 1

T denotes total failure, P partial failure, and D slight damage.

It will be observed that of the six total failures shown in Table III. as having taken place in the presence of ice, four have occurred in 1893 and 1894 within a period of slightly more than twelve months. This startling fact suggests the need of a prompt reform of such a character as will insure protection from this fruitful source of danger, but reform is clearly impossible except in so far as the

true elements of danger are known to those who have direct charge of this class of structures during actual operation. It should be stated that certain of the most powerful of the forces which may occur in the presence of ice are of so subtle a character and usually act so unexpectedly that distinct observations of their influence previous to actual rupture of the inclosing metal shell are almost entirely lacking. However, this deficiency may be largely supplied by a careful consideration of the meteorological and other conditions known to have existed at and for a sufficient period preceding the moment of failure. Although, as a rule, the stage of water in a stand-pipe is continually fluctuating, there are occasions when the water level may remain practically stationary for a considerable period of time. An instance of the latter condition is found in the case of Asheville, N. C., where the stand-pipe had been restricted to hold a reserve supply for fire purposes, and another in the case of East Providence, R. I., where the stand-pipe had been damaged by wind in its upper portion during construction and, pending final acceptance from the contractor, had been kept nearly full, probably for the purpose of preventing a repetition of the earlier accident. Since it is possible that an emergency requiring a fixed water level for a considerable period of time may occur in the life of almost every stand-pipe, due prominence should be given to this condition with respect to its influence upon the formation and action of ice. The following brief analysis of the phenomena of ice formation and action in stand-pipes is advanced in the hope of throwing some light upon this important subject.

With a fixed stage of water in the stand-pipe during a period of freezing weather, there may result:

(1) The formation not only of a sheet or cap of ice over the exposed upper surface, but also (2) the

formation of a tube of ice against the inner cylindrical surface of the metal shell, with (3) the thickness of the ice walls along any element of the cylinder probably about equal throughout its height, but (4) usually with a more or less eccentric horizontal section to the ice tube, because of the action of the sun or warm winds on the south side or of colder winds on the north side of the metal shell; and (5) it is important to observe that the connection between the ice tube and the rim of the bedplate will be watertight.

Now, with the ice cap and tube thus formed, we may have: (6) With a warmer period, melting may take place, beginning on the south side; (7) if the rise in temperature be sufficient in duration and amount, the ice tube will melt entirely loose from the stand-pipe; (8) the watertight connection with the base, mentioned in (5) above, will probably survive longest, particularly in case the water level is absolutely fixed; and (9) the water resulting from this melting will, of course, have a temperature of 32° F. and will trickle down between the two shells, forming a pocket having a height, perhaps, nine-tenths that of the ice tube.

(10) If, however, the melting loose be advanced only so far as to have formed a pocket or film of water on the south side of the stand-pipe between the ice and metal shells, and at this juncture (11) the process of melting is interrupted by a sudden reduction of temperature such as often occurs during a single night in the winter season, there would be (12) a re-freezing of the water contained in the isolated pocket above described, and this process would probably begin at the top and in the thinner edges of the film. As is well known, the congelation could proceed only so far as space for expansion were available; so that after the upper limit of the pocket had been closed, the process of freezing must cease, except as space is gained by stretching the outer metal shell or by deflecting or compressing

the inner ice arch, or both; for as above stated in (5) there is no communication at the base between the confined pocket and the main body of water within the stand-pipe.

Under these conditions (13) the strains produced in the metal shell are enormous, and in an extreme case immediate failure, either of the metal shell or of the ice arch, is highly probable. It is of interest to observe that (14) the strains may be materially increased by a rapid and considerable reduction of temperature which will contract the metal shell, although this element may be entirely nullified by a corresponding reduction in the ice tube from the same cause, and (15) the pressure of the inner body of water acts in a relatively slight degree to prevent the deformation of the arch and thus to increase the strain on the metal shell.

(16) The phenomena above described may occur in a mild form repeatedly in the same stand-pipe with little or no damage, or a weakness so developed may subsequently lead to the total failure of the structure at a time when the nominal strains are entirely insufficient to account for the failure. Reference to the descriptive record of ice failures shows that but two stand-pipes (Asheville and East Providence) have failed under the critical conditions above outlined, a fact which suggests the inquiry as to why no others have thus failed. The answer is found (17) perhaps mainly in the usual gradual fall of temperature which permits the full action of the plastic qualities of the ice tube, which thus conforms itself to the powerful expansive force. (It should here be stated that it has been found by careful experiments that the plasticity of ice is sensibly increased by the presence of air bubbles, such as exist in the ice which usually forms in stand-pipes, and it is also of importance to note in the same connection that the plasticity of ice is considerably greater at and very near the freezing point than below it. See Note A, p. 104.)

(18) The scarcity of such failures may also be

traced to the fact that the dangerous pocket always forms along the weakest line of the eccentric ice arch, and it is probable that the cracking sounds heard within both the stand-pipes above mentioned some time previous to their failure were due to the partial giving way of the ice tubes, thus proving that the force had been in action, perhaps intermittently, for a considerable period of time. It is thus seen that the eccentricity of the ice tube may act as a safety valve for the relief of this force, so as to avoid actual failure of the structure.

(19) Although no actual observations have been made to that effect, it seems entirely possible that water which had leaked into poorly filled rivet holes might lead to serious weaknesses, if not actual fracture, by freezing, provided the metal be so brittle in character as to have led to serious damage in the process of punching. The possibility of such damage would, of course, be much increased by "cold shortness" in the metal.

It is thus seen that this force is a most severe test of the quality of plate metal. Although the two stand-pipes which have thus failed were of steel, the magnitude of the bursting force was doubtless such as to render the kind or quality of plate metal of little importance. As to the amount of the force of freezing water, little of a definite character is known. A single test (made at Florence about a century ago), by bursting a 1-in. hollow brass globe, indicated that this force may exceed 30,000 lbs. per sq. in., and in a more recent test (made in Germany) with a cast iron bomb-shell, a force of about 6,000 lbs. per sq. in. was indicated. The measure of the force in each case was the tenacity of the metal, which is probably quite unreliable because of the uncertain extent to which the low temperature may have acted to modify its strength. The meager results of an extended search for records of this class of tests suggests the need of a series of experiments along this line to be conducted upon a reliable basis.

Considering now the more usual case of the fluctuating stage of water in the stand-pipe, there may result during a period of freezing weather:

(20) An ice cap usually quite thin in any particular sheet, but, owing to the formation of successive sheets, the ice accumulates in a thick but irregular mass within the limits of the daily fluctuations.

(21) A tube of ice forms against the inner surface of the metal shell, but (22) the thickness along any element of the ice cylinder is greatest at the cap mentioned in (20) above, and decreases downward.

(23) As in condition (4), with a fixed stage, the ice shell may also be more or less eccentric in the thinner portion, but the difference in thickness will probably not usually be noticeable in the irregular upper portion.

(24) The ice tube may originally form a tight connection with the bedplate, but the influx of warmer water soon melts the lower portion of the tube away or so reduces its thickness and strength (on the south side, at least) as to make the formation of an isolated pocket, such as is described in (9), quite improbable. (It is proper to mention a possible exception to this statement where the solar rays may be effectually cut off from the lower portion of the ice tube by the proximity of a building on the south side of the stand-pipe.)

(25) and (26). Same as for fixed stage (6) and (7).

(27) With the melting loose, the space between the ice and metal shells is directly connected with the inner body of water, and (28) the water in this connected pocket of course finds the level of the main body and quickly acquires a temperature of 32° F.

(29) With entire melting loose, the mass of ice floats freely, and with a full tank is buoyed up beyond the top rim of the stand-pipe, unless prevented from so doing by an obstruction at the top.

(30) If, while in this position, a sudden and considerable fall of temperature takes place, the ice

tube may freeze fast, and (31) if the water level is low at the moment when the mass of ice becomes detached (either by thawing, or by the action of gravity, or both) more or less damage and perhaps the total failure of the stand-pipe may result, depending, of course, upon the energy developed in the fall of the ice.

Returning to condition (20) it will be seen that (32) with weather of unusual severity a thick and perhaps airtight cap of ice may form during a brief period of fixed water level; (33) such an ice cap may prove to be a source of danger to the stand-pipe itself by an explosion similar to that which occurred in connection with the earlier Defiance, O., accident, or (34) it may seriously cripple the efficiency of the system in case of a fire or other sudden large demand upon the supply. These dangers from the ice cap may, of course, occur with either a fixed or a varying stage of water.

Returning to condition (28) we may have:

(35) With a sudden fall of temperature, the melted space may re-freeze, but without danger to the stand-pipe, because of the free connection between the main body of water and the pocket.

(36) With a continued reduction in temperature, the ice shell will contract more rapidly than the metal shell of the stand-pipe, owing to the fact that the coefficient of expansion of ice is several times greater than that of the metal, and this excess in the reduction of the ice tube will be displayed in the formation of cracks. These cracks immediately fill with water, which in turn is frozen, so that the ice tube may fill the metal shell perfectly at the lowest temperature.

(37) If it were now possible to raise the temperature of both ice and metal shells alike, a constantly increasing force would result from the excess in the rate of expansion of the ice, and rupture of the metal would soon result; but (38) it seems scarcely possible that the sun, which is, of course, the most powerful source of heat to be con-

sidered in this connection, can ever act with sufficient power upon the south side of a stand-pipe in the winter season to raise the temperature of thick walls of ice throughout to the point where this expansion will reach a critical stage, for either (39) the ice in contact with the metal would be melting by the time the temperature of the more remote ice were raised to the necessary point, or (40) the increase in temperature would be so gradual as to allow the plasticity of the ice, already mentioned, to relieve the pressure. As a matter of fact, it is probable that the temperature of the metal shell exposed to the direct rays of the sun is always enough above that of the contiguous ice to compensate for the above-mentioned excess in the rate of expansion of ice.

The foregoing outline of ice phenomena in stand-pipes is here presented for the first time, and it is doubtless not free from errors and omissions. The importance of the subject invites closer consideration than is here given to it, but the space required for other essential matters in this discussion forbids further extension of this interesting subject.

Perhaps the most striking and important fact developed by this classification is the relatively large number of failures in which the plates were of steel. In order to present this comparison in the most forcible manner, the accidents have been classed in Table IV. with reference to the kind of material in which the initial weakness developed; for in this inquiry it is, for instance, manifestly of little importance what kind of plate metal was used in the construction of the tank itself in the case of a stand-pipe whose failure was due to a defective foundation. Upon this basis, Table IV. shows that of the fifteen cases probably due in a direct manner to the failure of plate metal, twelve were of steel and three of wrought iron, nine of the former and two of the latter being total failures, and each of them occurred under water or ice strains, as shown by Table III. The contrast in the record of the

two metals is rendered perhaps even more striking by the excellent behaviour of the wrought iron plate under severe conditions in the case of the Stevens' Point accident, and also by the fact that during the construction of at least two of the steel stand-pipes (Sandusky and Cincinnati), numerous structural tests of the plate-metal were made and strict inspection of the work was enforced. In the same connection it is not improper to mention the defective design in the case of the Cleveland accident, and also to note that the failure of the wrought iron stand-pipe at Jersey City, in 1869, seems to have been partly due to damage sustained in erecting it by a method now obsolete. On the other hand, attention should be given to the fact that at least two of the failures of steel standpipes (Defiance and Asheville) due, in part at least, to defects in plates, were in every sense preventable on account of the distinct previous knowledge of the flaws.

The marked recent tendency toward the use of steel in stand-pipe construction seems, at first thought, in direct opposition to the above contrast in the past record of the two metals, which unmistakably favors wrought iron; but in addition to the facts presented in the foregoing record of accidents and failures, a just and complete comparison involves the consideration both of the respective stages of development in the processes of manufacture of the two metals, and also of the relative extent of their adaptation to this class of construction, at any given period. Upon this basis the excellent record of wrought iron above referred to seems mainly due to the fact that the process of making it had been brought to a high degree of perfection prior to its use for stand-pipe construction, while in the case of steel the grades ordinarily available during the earlier period of its use for this purpose lacked uniformity, and were often very deficient in the qualities essential to such construc-

tion. However, the rapid development in the art of steel-making, stimulated as it has been by the increased knowledge growing from the extensive use of the metal in all classes of structural work, has led to the present comparatively high degree of perfection in the processes by which uniform grades of steel having specified physical properties may be produced, and at a cost not only much less than formerly, but also low enough to successfully compete with wrought iron. Much light might be

TABLE IV.—Classification of Stand-Pipe Accidents and Failures with Reference to Kind of Material which Failed First.

Accidents and failures which occurred under pressure of water or combined ice and water strains.

Plate metal, steel.—Sandusky (P.), Sandusky (P.), Cincinnati (T.), Gravesend (T.), Seneca Falls (T.), Temple (T.), Defiance (D.), Defiance (T.), Asheville (T.), Maryville (T), East Providence (T), Peoria (T); Total, 12.

Plate metal, wrought iron.—Cleveland (T.), Jersey City (T.), Stevens Point (D.); total, 3.

Hoops, wrought iron.—Newport (T.), Nappanee (T.), Wheatland (T.); total, 3.

Inside ladder, wrought iron.—Greencastle (D.).

Collapsed at top or overturned by pressure of wind (see Table V.).

Steel.—Caldwell (P.); Asheville (D.), Plattsmouth (D.). East Providence (D.); total, 4.

Wrought iron.—Victoria (P.), Kankakee (T.); total, 2.

Failure of Masonry.

Brick tower.—Franklin (T.), Thomasville (P.); total, 2.

Concrete foundation.—Lexington (T.).

T. denotes total failure; P., partial, and D., slight damage.

thrown upon this comparison of the two metals by a complete and reliable record showing the dates of construction and the kind of metal used in each stand-pipe in the United States, but no such record complete enough to warrant definite conclusions has yet been compiled. A partial list of this kind, prepared and published in 1888 (see Manual of American Water-works, 1888), is classified in Table X.

The data presented in this table are, however, of

too meager a character to warrant anything beyond mere inference, since the compiler of the partial list from which it was prepared states that it "includes barely half the stand-pipes in the United States" (in 1888). The difficulties surrounding the collection of complete and entirely credible data of this class are very great; thus, for instance, of the 168 stand-pipes included in Table X. the date of construction is uncertain in 63 cases (38%), and the

TABLE X.—Classification of a Partial List of Existing Stand-Pipes in the United States in the Year 1888. with Reference to Date of Construction and Kind of Metal.

Year.	Steel.	Wrought iron.	Steel & w. i.	Un-certain.	Total.
1854	..	1	..	..	1
1860	..	1	..	..	1
1861	..	..	..	1	1
1868	..	1	..	..	1
1872	..	1	..	..	1
1874	..	1	..	..	1
1876	1	..	..	..	1
1877	..	2	..	..	2
1878	..	..	..	1	1
1880	..	3	..	..	3
1881	..	2	..	..	2
1882	2	5	..	1	8
1883	1	6	..	1	8
1884	1	12	..	..	13
1885	1	18	..	..	19
1886	6	17	1	..	24
1887	6	7	..	..	13
1888	2	1	..	2	5
Uncertain	2	22	..	39	63
Totals	22	100	1	45	168
"Certain" tot'l	20	78	1	..	99

kind of plate metal used is lacking in 45 cases (27%). Cutting out the uncertain figures, there remain 20 steel, 78 wrought iron and one combination stand-pipe, from which it may perhaps be inferred that in 1888 the number of steel stand-pipes in the United States was about one-fourth of the number built of wrought iron, which, if true, makes the superior record of the latter metal even more striking. It appears from Table X. that steel was first extensively applied to the construction of

stand-pipes about 1886, for of the 20 steel stand-pipes whose dates are given, 14, or more than two-thirds, were built in 1886, 1887 and part of 1888, while in the same period the decrease in the number of wrought iron stand-pipes built is very distinctly shown, being 18 in 1885, 17 in 1886, 7 in 1887 and but one in the part of 1888 included in the table. Allowing for a reasonable discrepancy in the above figures, it is still quite apparent that the growing preference for steel which has prevailed in other classes of construction for the past few years has also largely controlled the construction of stand-pipes. No record of the number of stand-pipes built since 1888 is available, but it has recently been stated that "there are now seven or eight hundred stand-pipes in the United Sates, and their number is rapidly increasing." If, as estimated, the stand-pipes, 163 in number, listed in 1888, were about one-half the total number, there were at that time perhaps 350 such structures in the United States, which indicates that the number has doubled in a period of about six years.

A complete record, brought up to date, along the lines suggested by Table X. seems at first thought to be much needed, but in reality the value of such a record would be largely nullified by the fact that the mere name, steel or wrought iron, is after all of little value as a measure of quality, notwithstanding a popular belief to the contrary. It is at this time highly important to give due consideration to a very significant effect upon the quality of wrought iron, which has been a direct result of the recent marked preference for steel in structural work. With the decline in the use of wrought iron, the reduced attention to its manufacture has led to such serious deterioration in quality as to even suggest that the superior past record of wrought iron in stand-pipe construction might soon be appreciably affected, or perhaps even reversed, in the event of a sudden resumption of the earlier preference for that metal for this purpose, unless a corresponding

restoration of its former excellent quality was at once brought about. But with the present decided preference for steel in other classes of structural work, based largely, as it is, upon much reduced prices, and with the constant decline in the output of wrought iron as compared with steel, the probability of an exception being made in a single class of structures is very remote. If, as indicated by the meager statistics above given, the number of stand-pipes has been doubled within a period during which a decided preference has been shown for steel, it is probable that the contrast in the record of failures will continue to favor wrought iron, for, while many stand-pipes have been built with steel of suitable quality, a very considerable number have been constructed from "tank" steel. The latter grade of steel has perhaps led to a majority of the failures of steel stand-pipes and, because of its extended use in the past, will doubtless cause many others. The tensile strength of "tank" steel is frequently higher than is required, but its brittleness and low ductility render it liable to damage in the process of punching and sudden failure is apt to take place, particularly at low temperatures.

The use of an inferior grade of steel is, as a rule, the result primarily either of deficient or defective specifications, or in case proper quality and efficient tests are specified, the tests are omitted. The former is much too often the case, for even in the better practice it is by no means uncommon to find specifications for plate metal which merely fix the tensile strength with no reference whatever to other equally essential physical properties; or if tests are mentioned, their character is often such as to admit grossly defective material even if rigidly enforced. Loose specifications and methods of construction are also sometimes the outcome of a tacit understanding between a construction company and the contractor, by which a considerable saving is effected in the first cost of the stand-pipe at the expense of safety. As long as such practices are per-

sisted in there is little hope for reform, and the stand-pipe will more and more become a menace to the very interests that it was designed to promote.

It is unquestionably practicable to construct a stand-pipe, either of steel or of wrought iron, which will be as safe as any other structure built from the same metal, provided like care is taken both in the original design and construction, and also in the subsequent operation and maintenance. However excellent the method of design and construction may be, it is, of course, vitally important to provide protection for the structure under certain critical conditions which have been described in the record of failures. The most critical of the emergencies which may occur in the life of a stand-pipe have been described in connection with the discussion of "ice" accidents. A clear conception of those emergencies leads to the belief that stand-pipe shells may be subjected to strains at least equal to, and probably at times much exceeding, those which may occur in the shells of high-pressure steam boilers. Adding to this the well-known treacherous action of steel of a brittle character (particularly high phosphorous steel) under low temperatures, the conclusion is reached that the standards of quality, both of material and workmanship, which govern high-grade boiler construction, should also prevail in the construction of stand-pipes. This standard, or its equivalent, has already been adopted by the more enlightened and progressive engineering practice. the tests of quality being based upon the actual conditions in the structure, and being so conducted as to afford conclusive evidence of the quality. It is scarcely necessary to remark that the responsibility of the designing or consulting engineer with respect to the enforcement of the proper quality of design, material and workmanship, should not be construed to cease with the completion of the structure. Considering all phases of

the question, it seems proper to conclude that future practice may wisely continue to favor the use of steel in stand-pipe construction, provided the actual conditions to which the structure may be subjected are clearly recognized, and also that the details of the design, the grade of steel, and the class of workmanship, which will most effectually meet those conditions, are utilized with intelligence.

Returning to the discussion of Table IV., three cases of elevated wooden tanks whose failures were due to bursting hoops, suggested the need of caution in adjusting the tension of the hoops to stop the leakage, on account of the increased strain caused by the swelling of the staves. In the absence of definite knowledge as to the dimensions and quality of the hoops, the true source of weakness cannot be assigned, but it is very probable that the usual errors of detail in the joints were not lacking. The scope of this record was not extended to include the failure of wooden railway tanks, of which a number have taken place, because of the fact that the three cases which have been described fully present the more common elements of danger encountered in the use of this type of tank.

The failure of the concrete footings under the supporting columns of the Lexington stand-pipe forcibly suggests the danger due to unequal settlement of isolated pieces of masonry, particularly where the presence of water may soften the substratum. This failure and those of the two brick towers urge the need of proper methods both in the design and in the construction of this class of masonry.

Before considering the next table, reference should be made to the characteristic phenomena which accompany the failure of relatively tall stand-pipes in which the initial fracture occurs near the base, as exemplified by the ruins themselves. A careful study upon the latter basis develops the fact that the stand-pipe is usually separated into three principal portions, viz.: (1) the

foundation and bed-plate, generally left undisturbed except as to cuts and bruises in the latter, which are caused by falling plates; (2) a more or less demolished mass of plates, consisting usually of less than the lower half of the stand-pipe, and which, in general, is projected in a direction diametrically away from the point of initial rupture; and (3) the remaining upper portion which topples in the approximate direction of a radial line passing through the point of first rupture. In addition to the above, isolated fragments which are frequently projected to considerable distances, may offer important suggestions as to the point of first failure. It should be remarked that the second observation, or rather a modification of this observation as above stated, may often serve as available evidence in relation to the quality of plate metal, for when the metal is unusually brittle, it is found that the lower portion of the structure bursts into a number of individual fragments of large size, instead of clinging together as above stated. An exception to the third also has been observed in one case in which the direction taken by the unruptured top portion was sensibly modified by the action of the wind.

Table V is a special record of the six cases due to wind action, of which four were of steel and two of wrought iron, as shown in Table IV. The opinion seems to be entertained in some quarters that special anchorage is not necessary, except perhaps in the case of tall stand-pipes having small diameters. If this idea is based upon the belief that the empty tank has sufficient weight to counteract the wind moment, it is certainly not confirmed by the East Providence accident, where, with an unusually heavy structure, the force of the wind was strong enough to sensibly lift the windward side; and, furthermore, a similar occurrence has been observed in the Eastern States with other stand-pipes for which no anchorage had been provided.

Or, possibly, the above mentioned practice assumes that the probability of having an empty stand-pipe and a severe wind storm simltaneously is too remote to require special provision. Such assumption finds no support in the record, for it is a significant fact that nearly one-fourth of the entire number of accidents which have been described have occurred during violent wind storms, and that, with one exception, the stand-pipes were entirely empty. On the other hand, it may be noticed that the structures actually overturned were in but two out of the five cases of entirely empty stand-pipes, although two others (Plattsmouth and East Providence) rocked with more or less violence upon their foundations. Of the four stand-pipes whose bearings were thus disturbed, three were anchored, a fact which urges the need of making the anchorage more secure. In this connection reference should be made to the undoubted advantages which may be had by the use of well designed bracket anchorages in the case of tall stand-pipes of small diameter. This necessity for a rigid connection between the stand-pipe and its foundation is by no means confined to the tendency to overturn, for it also bears an important relation to the vibration of the structure, which may lead to the collapse in the upper portion. Thus, for example, it is a matter of some doubt whether the stand-pipe at Plattsmouth would have collapsed had its anchorage remained firm, and in the case both of Kankakee and East Providence the vibrations of the plates were doubtless aggravated by the rocking too and fro upon the foundation.

In considering the question of overturning and collapse of stand-pipes, it would, at first thought, seem very important to know the actual velocity of the wind at the moment of failure, but aside from the interest in the figures as a part of the record, they are not of great utility; for, as a matter of fact, the danger to the stand-pipe probably depends less upon the actual intensity of the wind

pressure than upon the accumulation of force by coincidence of gusts of wind with the vibrations of the tank. To the latter condition probably more than to anything else may be ascribed the failures to reach practical results in the various attempts which have been made to place the above problem upon a theoretical basis. The idea has been advanced that collapse is partly due to rarefaction of the air within the stand-pipe, but even if the difference in pressure were sufficient to have appreciable influence, it would seem to be secondary in importance to the vibratory tendency above mentioned. Considering this uncertainty, it is not surprising that there has been much lack of uniformity in providing stiffness in the upper portion of the stand-pipe; for, as a rule, the minimum thickness of plates and the dimensions of the stiffeners are fixed either by precedent or according to the judgment of the designer.

Table V. also shows that collapse took place in five out of the six cases and that, with one exception, the stand-pipes were entirely empty. In the case of the Victoria collapse, in which only the empty portion failed, the storm was of unusual violence, but the occurrence shows that safety against such an accident may be had only with a full stand-pipe. It is also a striking fact that four of the six accidents occurred either during construction or in the interval between completion and first test, a critical period which must of necessity occur with every stand-pipe. It would seem that the system of floating derrick construction, used with success in a number of instances, is admirably adapted to the needs above mentioned, although its original adoption and subsequent use have, of course, been based upon a quite different requirement. Thus, for instance, in the case of the East Providence stand-pipe, had the contractor used a floating derrick (as the sub-contractor for the roof of the same structure is said to have done) the collapse of the upper portion and, under the circumstances, perhaps

TABLE V.—Special Record of Stand-Pipe Accidents and Failures due to Action of Wind.

	Caldwell.	Victoria.	Kankakee.	Asheville.	Plattsmouth.	E. Providence.
Diameter, feet	12¼	16	20	45	25	40
Height	150	100	124	60	80	120
Kind of plate metal	Steel.	Wrought iron.	Wrought iron.	Steel	Steel.	Steel.
Existing conditions	During const'n; empty.	Top 30 ft.; empty	Just completed; empty.	Just completed; empty.	During repairs; empty.	During const'n; empty.
Manner of failure	Overturned.	Collapsed.	Collapsed and overturned.	Collapsed.	Collapsed and anchor bolt broke.	Collapsed.
Thickness of plates in collapsed portion.	....	30 ft., $^3/_{16}$ in.	24 ft., ⅛ in.	20 ft., ¼ in.; (?) ft., ⅜ in.	24 ft., $^3/_{16}$ in.; 8 ft., $^7/_{32}$ in.; 8 ft., ¼ in.; 8 ft., $^9/_{32}$ in.; 4 ft., $^5/_{16}$ in.	20 ft., $^5/_{16}$ in.; 15 ft., ⅜ in.
Top stiffening angle	(?)	(?)	3 × 3 × ½ ins.	3 × 3 × ½ ins.	2 × 2 ins., punched.	None.
Anchorage	Guys.	Brackets.	6, 1½-in. bolts.	None.	4, 2-in. bolts.	None.
Probable max. vel. of wind (miles per hour)	(?)	80	60	(?)	70	60

See important revision of wind velocities in the cases of Kankakee and Plattsmouth in Table XI., Append I.

the final failure as well, would have been obviated.

Aside from the facts presented in Table V. an important effect of the wind in the case of tanks of large diameter should here be mentioned. Referring to the descriptions of the Cincinnati, Asheville and East Providence failures, it will be found that the tanks, having diameters of 100 ft., 45 ft. and

TABLE VI.—Classification of Total Failures, with Reference to Life of Stand-Pipes and Material.

Failed previous to test.

Kankakee, Ill..........................Wrought iron

Failed during test.

Cleveland, O.	Wrought iron	Temple, Tex..........	Steel
Cincinnati, O.........	Steel	Nappanee, Ind.......	Wood
Lexington, Ky....	Masonry	Wheatland, Ia.......	Wood
Gravesend, N. Y......	Steel		
Newport, Ark........	Wood	Total	8

Failed after test.

Jersey City, N. J.............	Wrought iron	10 years
Franklin, Man.	Masonry	4 weeks
Seneca Falls, N. Y..................	Steel	4 months
Defiance, O.	Steel	2 years
Asheville, N. C.......................	Steel	6 years
Maryville, Mo.	Steel	6 years
East Providence, R. I................	Steel	4 months
Peoria, Ill.	Steel	4 years
Total	8	....

Summary.

Steel	9
Wrought iron	3
Wood	3
Masonry	2
Total	17

40 ft.,respectively, are believed to have been weakened by the continuous vibratory action of the wind upon the plates. In the first instance the tank had been exposed to the heavy winds for a considerable period during its construction and it failed in its first test; in the second case guys were added after visible damage from the same cause some two years before the final failure took place under ice strains; and in the last named case the sides had been violently vibrated during a series of wind storms

while empty during construction about 4½ months previous to the final failure.

It is, of course, needless to say that, in the main, the above observations do not apply to tanks which are encased in masonry or are otherwise effectually protected from the direct action of the wind.

The classification of total failures in Table VI. is made with reference to the life of the stand-pipe,

TABLE VII.—Classification of Stand-Pipe Accidents and Failures with Reference to Location by States.

	Existing conditions and extent of damage.								Summary.			
	Water.		Ice.		Wind.			Other.				To-
	T.	P.	T.	D.	T.	P.	D.	P.	T.	P.	D.	tal.
Arkansas	1	..	..	..	..	..	..	..	1	..	..	1
Georgia	..	..	..	..	..	..	..	1	..	1	..	1
Illinois	1	..	..	..	1	..	..	..	2	..	..	2
Indiana	1	..	..	1	..	..	..	..	1	..	1	2
Iowa	..	..	1	..	..	..	..	..	1	..	..	1
Kansas	..	..	..	..	..	1	..	..	..	1	..	1
Massachusetts	1	..	..	..	..	..	..	..	1	..	..	1
Missouri	1	..	1	..	..	..	..	..	2	..	..	2
Nebraska	..	..	..	..	..	..	1	..	..	..	1	1
New Jersey	..	..	1	..	..	..	..	..	1	..	..	1
New York	2	..	..	..	..	..	..	..	2	..	..	2
N. Carolina	..	..	1	..	..	..	1	..	1	..	1	2
Ohio	2	2	1	1	..	..	..	..	3	2	1	6
Rhode Island	..	..	1	..	..	..	1	..	1	..	1	2
Texas	1	..	..	..	..	1	..	..	1	1	..	2
Wisconsin	..	..	..	1	..	..	..	..	..	..	1	1
Totals	10	2	6	3	1	2	3	1	17	5	6	28

T denotes total failure, P, partial, and D, slight damage.

that is, as regards the relative times of first test and of failure. It will be noted that one failure occurred previous to test and that eight failed during test. In the remaining eight failures the life varied from four weeks in the case of the brick supporting tower at Franklin to ten years in the Jersey City stand-pipe, and was six years in two other cases. This leads to the important observation that no assurance of safety is to be found in the mere fact that any given stand-pipe has stood

for several years without visible signs of weakness. Reference has already been made to the contrast in the number of steel and wrought iron stand-pipes which have failed totally; this fact is also shown in Table VI. in the summary column.

Tables VII., VIII. and IX., class the accidents with reference to existing conditions and extent of damage in connection with location by state, date by month and date by year, respectively.

Table VII. presents the fact that the distribution

TABLE VIII.—Classification of Stand-Pipe Accidents and Failures with Reference to Date by Month.

	Existing conditions and extent of damage.								Summary.			
	Water.		Ice.		Wind.			Other.				Total
Month.	T.	P.	T.	D.	T.	P.	D.	P.	T.	P.	D.	
January	..	..	3	1	..	..	..	..	3	..	1	4
February	..	..	1	1	..	..	..	..	1	..	1	2
March	1	..	1	1	..	..	1	..	2	..	2	4
April	..	..	..	..	..	..	1	..	..	..	1	1
May	1	..	..	..	..	..	..	..	1	..	..	1
June	2	..	..	..	..	1	..	..	2	1	..	3
August	1	..	..	..	..	1	..	..	1	1	..	2
September	..	..	..	..	..	..	1	..	..	..	1	1
October	4	1	..	..	1	..	..	..	5	1	..	6
December	..	..	1	..	..	..	..	1	1	1	..	2
Unknown	1	1	..	..	..	..	..	..	1	1	..	2
Totals	10	2	6	3	1	2	3	1	17	5	6	28

T denotes total failure, P, partial, and D, slight damage.

of accidents under each cause has been quite general. Perhaps the most striking feature of this table is the failure due to ice strains as far south as North Carolina, the explanation of which may be found in the high altitude of Asheville, where the acciddent occurred. It is also of interest that four of the six accidents due to wind pressure have occurred in the West.

Table VIII. shows that the number of accidents which have occurred in the month of October is greater than that of any other month, but, by tracing the record of the six cases, it is found that two

of the accidents occurred during first test and a third previous to test, so that the excess in October is due to the fact that several initial tests have chanced to be then made, and not because the conditions have been actually more severe during that month. It is also seen that all the wind accidents have taken place from March to October, inclusive, and that the ice accidents have been practically confined to January, February and March, the one exception having occurred on Dec. 31. Since the water accidents have occurred mainly during first test nothing of special interest concerning them is shown in Table VIII.

TABLE IX.—Classification of Stand-Pipe Accidents and Failures with Reference to Date by Year.

Year.	Existing conditions and extent of damage. Water. T.	Water. P.	Ice. T.	Ice. D.	Wind. T.	Wind. P.	Wind. D.	Other. P.	Summary. T.	Summary. P.	Summary. D.	Total.
1868	1								1			1
1869			1						1			1
1877(?)		1								1		1
1878		1								1		1
1881	1								1			1
1885	1								1			1
1886	1				1	2			2	2		4
1887	3						2	1	3	1	2	6
1889				1							1	1
1890	1								1			1
1891			1	2					1		2	3
1892	1								1			1
1893			3				1		3		1	4
1894	1		1						2			2
Totals	10	2	6	3	1	2	3	1	17	5	6	28

T denotes total failure, P, partial, and D, slight damage.

Table IX., giving the date by year, is chiefly of interest in a historical sense, the most striking feature being the well-known epidemic of stand-pipe accidents and failures which took place in 1886 and 1887, the largest number, six, having occurred during the latter year. It is also seen that four cases occurred in 1893, equal in number to those in 1886,

although it should be noted that the greatest number of total failures within a year is three, there having been this number both in 1887 and 1893. Attention has already been drawn to the startling fact that of the six total failures which have taken place in the presence of ice four have occurred in 1893 and 1894.

In conclusion, it seems proper to mention the several lines of apparent need for reform suggested by the foregoing record. While the maximum attainment of safety must continue to come through the rigid and intelligent enforcement of high quality, both of material and workmanship, the element of design also offers a broad field for improvement. The question of quality is provided for in the strict system of test and inspection which govern other classes of structural work, and too much stress cannot be placed upon the rigid enforcement of properly worded specifications. Probably the most urgent need for improvement in design is suggested by the large number of total failures which have occurred under the two heads of water and ice. A consideration of the liability of the more common type of stand-pipe to fail near its base, in connection with the matter of effective storage, first led to the use in this country of the elevated tank. Subsequent consideration of the elements of economy of construction and, in some instances, of architectural effect, has led to modifications of form in the supporting framework or tower, and also, to a limited extent, to the adoption of the several types of tank bottom, which originated in the German practice. In addition to the above questions there also seems to be room for improvement in the method of construction. In the latter connection the floating derrick system (see reference in note B, p. 105), seems particularly promising in view of the large number of total failures which have occurred under hydrostatic pressure during first test; for, as is well known, a flaw which may prove fatal under a suddenly applied load might either be detected or prove harmless under the same strain gradually applied.

The danger from ice suggests the need of measures to prevent its formation, to which end the simplest and best device, although often expensive, is the enclosure of the tank, leaving an air space to secure insulation (this expedient has recently been applied with success to several exposed stand-pipes which had previously been endangered by ice formation). Although this plan entails a considerable increase of cost, it has an advantage which is too often overlooked in that it affords a means of providing for the architectural effect in a manner superior to the metal cylinder. The elements just mentioned may often be served in an efficient manner by the use of a roof which, besides reducing the tendency to form dangerous ice caps, will also exclude the direct rays of the sun, the influence of which upon some water supplies in promoting vegetable growths so as to cause objectionable tastes and odors in the stored water, is well known. It is important, however, to consider the possible danger to the roof and perhaps to the entire structure in those localities where ice forms in excessive quantities, by the buoyant tendency of the mass of ice after it has melted loose. Still another advantage in the use of the roof may be found in those cases of low tanks which may be accessible to mischievous parties as receptacles for polluting matter of various kands, although the large diameters of many such low-level storage tanks may suggest the use of a less expensive means of abating such a nuisance. The necessity for excluding all obstructions from the interior of the stand-pipe, which has already been discussed, is easily provided for in making the design. The wind accidents, as already stated, suggest the need of firm anchorage and also urge liberal provision for rigidity in the upper portion of the stand-pipe. The latter consideration may, as a rule, be provided for in ordinary cases by using plates of reasonable thickness, but as the diameter becomes large the thorough protection of the structure while empty seems to

demand the use of guys or an equivalent means of reducing the vibrations due to wind. A consideration of the latter element in connection with the uncertainties of quality which exist in excessively thick plates suggests that a recent tendency toward the combination of a large diameter and a considerable height in the same stand-pipe is not wise, although such a design may somtimes be necessary. Recent tests of riveted joints in soft steel plates have strikingly shown the damage resulting from punching rivet holes in thick plates and some engineers have been led to specify that all plates above ¾-in. in thickness shall be drilled, or if punched that the holes shall be reamed, and one recognized authority has also taken into consideration the change in character of the fracture due to the punching and has placed the limit at ½-in. (an examination of the table of stand-pipes in the United States in 1888, already mentioned, shows that of 136 cases in which the thickness of the first course of plates is stated, in only 13 (or 10%) of them did the thickness reach ¾-in.and of the latter in only five cases was that thickness exceeded.) It is also quite generally believed that ⅞-in. or 1-in. is the maximum thickness of plate which can be satisfactorily riveted up by hand in the field and such a limit should be observed in the stand-pipe design. In addition to the questions of design and construction that of operation also deserves attention, particularly in the presence of ice in large quantities. Under the latter conditions the necessity for frequent pumpings during severe freezing weather and for avoiding low stages of water during a thawing period should be clearly recognized and provided for.

While many points of interest have doubtless been presented in the foregoing record and classification, the real value of the inquiry must, of course, be measured by the light which it may afford for the guidance of future practice.

Note A. The Plasticity of Ice.—In discussing the action of ice in stand-pipes, it was stated (p. 81) that the readiness with which ice undergoes deformation undoubtedly has an important influence in reducing the danger to which stand-pipes are liable from the presence of ice. Various experiments made primarily for the purpose of throwing light upon glacial action also have an important bearing in this connection. The results of the more reliable of these experiments have appeared in "Nature" from time to time, reference to which is made as follows: Vol. I., p. 534; Vol. IV., p. 447; Vol. VI., p. 396; Vol. VII., p. 287; Vol. XII., p. 317; Vol. XXXI., p. 329; Vol. XXXII., p. 16, and Vol. XLII., p. 213.

The above reference to Vol. XXXII. of "Nature" is of particular value in that the writer, Morgan, reviews previous experiments besides giving the results of his own tests of the "viscosity" of ice. In the reference to Vol. XLII. (abstract from the "Royal Society Proceedings") the experimenter, Andrews, concludes that "if the plasticity of ice at $-35°$ F. be taken as unity, that at 0° F. $= 2$, and at 28° F. $= 8$." From the last named temperature up to 32° F. this property must increase very rapidly, for Prof. Pfaff had previously (1875; see "Nature," Vol. XII, p. 317) found "that even the smallest pressure is sufficient to dislocate ice particles if it act continuously, and if the temperature of the ice and its surroundings be near the melting point." Pfaff also found that the presence of air bubbles has a marked influence in augmenting the plastic action of ice.

If the above-mentioned relation between porosity and plasticity of ice be considered in connection with the well-known prevalence of air bubbles (frequently in large quantities) in freshly pumped water, important light is thrown upon the failures of the Asheville, N. C., and the East Providence, R. I., stand-pipes, for in both instances the quality of the ice tubes must have been exceptionally

dense, and hence unyielding, because of the fact that pumping had not been in progress during the period of ice formation.

Furthermore, the marked increase of plasticity near the freezing point, above mentioned, goes far to explain the scarcity of accidents of the class discussed on pp. 80-82, under conditions (10) to (17), inclusive.

Note B. The Introduction of the Floating Stage for Erecting Stand-Pipes.—A careful investigation indicates that the system of erecting stand-pipes by means of the floating stage or derrick was first introduced in 1876 by Mr. J. D. Cook, Hydraulic Engineer, in the construction of the 25×180-ft. steel stand-pipe at Sandusky, O. In that case an outside staging from the ground was used, from which the rivets were driven, the rivets being held by workmen on the float. The outside staging was first dispensed with, it is claimed, by Mr. J. C. Chase, C. E., in making a 20-ft. extension to the 20×70-ft. wrought iron stand-pipe at Wilmington, N. C., in 1882. In the latter case, "the rivets were driven on the inside, and held on the outside by a workman suspended in a cage, carried by roller hooks traversing the top edge of the course of sheets on which work was being done." Mr. Cook states that commencing with the 25×132-ft. stand-pipe at Atlantic City, N. J., built in 1883, he also dispensed with the outside staging, and that he has since used the floating stage in erecting all stand-pipes of large size. It has been his custom throughout to use a double decked float, "the upper deck being occupied by the riveters, and the lower deck by the painters, the painting being kept above the water-line." Numerous stand-pipes of various sizes have been erected by this admirable system within recent years and there is reason to believe that it is growing in favor.

APPENDIX I.

SUPPLEMENTARY RECORD.

It is the purpose of this Appendix to give a supplementary record of stand-pipe accidents which were overlooked in the preparation of the original record or have occurred since the previous matter was put in type. In the progress of this later inquiry, as indeed was true of the former as well, several false rumors of stand-pipe accidents have been investigated, and by the co-operation of local authorities, confirmed where practicable through independent channels, such cases have been carefully excluded from these pages.

Because of the limited number of cases here presented, no regular classification will be attempted. It is of much interest to notice that a classification of the cases here described along the lines followed in the original record would require a quite different set of headings in the matter of "cause." While several of these accidents resulted in little or no damage, they do not lack interest for that reason alone. In the discussion which concludes this Appendix, attention is drawn to the more important lessons to be learned from the supplementary record.

Chicago, Ill., 1854.

A brick tower, 136 ft. in height, enclosing a 2-ft. cast and wrought iron stand-pipe, which was built in connection with the water-works at Chicago, Ill., in 1854, was found to be leaning to the eastward, and the settlement continued until the top of the tower had left its original position about 14 ins. The plan of the tower was a hollow square, the outside dimensions being 14 ft., 13 ft. and 11 ft., at the bottom, middle and top, respectively, the reductions being made by exterior offsets. The stand-pipe was cast iron in its lower 100 ft. and was made of ¼ in. wrought iron in the upper 36 ft.

The space between the pipe and the enclosing tower was utilized as a smoke channel.

The foundation of the tower consisted of masonry work resting upon a layer of sand 6 ft. below the surface, and the settlement above mentioned was found to be due to the unequal yielding of this stratum of sand. Adjoining the tower on the east side was the foundation of a pumping engine, established on piles spaced 3 ft. apart, the area covered being 32 × 42 ft., or 1,344 sq. ft. The engine foundation being on the side toward which the tower leaned, it was utilized in restoring the structure to its original position. A groove was cut into the foot of the brickwork on the east side and a double row of long wrought iron wedges was inserted, their butts resting upon the engine foundation. The east side of the tower was thus slightly lifted and close watch was kept upon the settlement as it continued on the opposite side. As required, the wedges were gradually removed until the settlement finally ceased altogether with the groove in the brickwork closed and the tower plumb. No damage resulted to the tower and it stood without further movement until in 1867-8 it was abandoned and removed.

References.—Andreas' History of Chicago, p. 188. Correspondence in 1894 with Mr. D. C. Cregier, of Chicago. Mr. Cregier was connected with the Public Works Department of the City of Chicago for an extended period, beginning in 1853, and is also the authority for the information concerning the above incident, found in the Manual of American Water-Works for 1888, p. 370, and for 1889-90, p. 438. The former is in error in giving the deviation of the top of the tower as 14 ft., while, as stated correctly in the latter reference, it was in reality 14 ins.

Erie, Pa., 1872.

A striking instance of the buoyant action of ice in a stand-pipe has been observed at Erie, Pa. The stand-pipe referred to is 5 ft. in diameter and when built in 1868 had a height of 220 ft. During the first year or so after its completion the stand-pipe was held in place by ¾-in. guy rods, after which it was encased by a brick tower. The

following description of the experience with ice, above referred to, has been obtained through the courtesy of Mr. Wm. W. Reed, M. Am. Soc. C. E., who was the first president of the Erie Water-Works:

In enclosing the stand-pipe we built the brickwork about a foot above the top of the pipe and floored it over. A railing was put on the outside, thus making a splendid view for those strong enough to ascend the 220 ft. of steps between the stand-pipe and the masonry enclosing it. As the pipe was entirely enclosed, we did not think it necessary to heat the space between the pipe and masonry in cold weather.

A few years after the works were put in operation we had a very cold winter, causing a cylinder of ice to form around the sides of the pipe, perhaps 8 or 10 ins. in thickness. When the weather grew warmer the ice loosened from the pipe and, rising by its buoyancy, knocked the platform off and sent a cylinder of ice 20 ft. or more above the top of the pipe. Within an hour of the time this happened two persons had been taking a view from the top of the stand-pipe. Had they been an hour later they would have met their death in a fall of 230 ft. After this we added 6 ft. to the pipe, letting it project above the platform, thus obviating danger of the kind above described. The present height of the stand-pipe is about 251 ft., extensions having been made from time to time.

It is obvious that the danger here described demands close consideration not only from those responsible for the safe use of stand-pipes, but also from the designer who may favor the practice of roofing them. It is, moreover, a fact which invites studious attention, that a brick casing with an intervening air space should have permitted the formation of ice to the extent above recorded. In seeking an explanation of this fact, it should be noticed that the conditions existing in the case under consideration seem to have been abnormal, not only as regards the small diameter and great height, but also in relation to the much-exposed site and the extreme severity of the season. The last-named element must have effeeted both a reduction in the temperature of the water pumped into the stand-pipe and also an increased rate of radiation of heat from the stored water.

References.—Correspondence with Mr. Wm. W. Reed, M. Am. Soc. C. E., Erie, Pa. (1894).

Wilmington, N. C., 1881.

A 20 × 70-ft. wrought iron stand-pipe, which was built in 1881, at Wilmington, N. C., had no metal bottom or anchorage. It appears that the stand-pipe was designed without engineering assistance of any kind, and that the bottom was left out to reduce the cost, the contractor claiming that it was unnecessary. Two unsuccessful attempts were made to secure a tight connection at the bottom: First, by means of a 12-in. bed of concrete inside the stand-pipe, and again by calking a joint in lead which was poured into a recess picked into the masonry, around the rim under the base angle. A third and successful attempt was made by putting a wooden bottom into the stand-pipe. This bottom or floor was made of two thicknesses of 3-in. yellow pine plank, laid so as to break joints, all joints being filled with oakum, and then coated with pitch, and was laid on a bed of cement mortar. To prevent the bottom from floating, short braces bearing against the second course of plates were inserted.

This seemingly unimportant incident is here presented as an illustration of the absurd practice which may be imposed upon well-intentioned parties through their failure to employ competent professional advice.

(This stand-pipe was extended to a height of 90 ft. in November, 1882, by means of a floating staging.)

References.—Engineering News, Vol. X., p. 153 (March 31, 1883); Vol. XXIX., p. 578 (June 22, 1893). Journal of the New England Water-Works Association, 1893, p. 68. Correspondence in 1894 with Mr. J. C. Chase, M. Am. Soc. C. E., Superintendent and Engineer Clarendon Water-Works Co., Wilmington, N. C. (who took charge of the works after the stand-pipe had been erected).

Holbrook, Mass., October, 1887.

In October, 1887, during a gale of wind, the 30 × 112-ft. wrought iron stand-pipe at Holbrook, Mass., was lifted repeatedly about three-fourths of an inch on the windward side, although no damage whatever resulted either to the tank or the foundation.

The following facts relative to the incident are given by Mr. Freeman C. Coffin, M. Am. Soc. C. E., who was principal assistant to Mr. M. M. Tidd, M. Am. Soc. C. E., the Engineer of the Holbrook Water-Works:

> Mr. Tidd had requested the commissioners to have some water pumped into the tank with a steamer (the stand-pipe having just been completed and connection with the mains not having yet been made), as he feared the wind; but they thought his fears unnecessary, and allowed it to remain empty. I was in Holbrook on the day of this high wind and visited the pipe to see the effect. I found that with each strong gust the pipe rocked upon the foundation and lifted on the windward side about ¾ in. I immediately got one of the commissioners to go there and see it, after which he hastily secured the town steamer and about 1,000 ft. of hose and pumped about 12 ft. depth of water into the tank from a small adjacent pond. This held the pipe firmly to the foundation until the pumping plant was completed.
>
> I do not think that any wind that we have here would have blown it over, but I was afraid of the action on the foundation. I noticed no vibration of the sides. The top was thoroughly stiffened by an angle iron.

Mr. Coffin is unable to give an estimate of the velocity of the wind at the time, but the following record of maximum wind velocities, recorded at Blue Hill, about six miles from Holbrook, furnished by Mr. William Jackson, M. Am. Soc. C. E., City Engineer of Boston, from the New England Meteorological Report for 1887, may serve to throw some light upon the matter; corresponding figures for Boston, from the "U. S. Monthly Weather Review," are given in the second column:

	Maximum wind velocity, miles per hour.	
	Blue Hill.	Boston.
September	35	30
October	54	40
November	49	42

The three months are given owing to a possible uncertainty as to the exact date of the occurrence at Holbrook.

In neither of the above is it stated whether the recorded velocities are the actual maxima or the maximum average velocities for an hour. It seems

probable that the velocity of the wind at the time of the incident under consideration was, upon the basis of the above records, in the neighborhood of 50 miles per hour.

Through the courtesy of Mr. Thomas Cunningham, General Manager of the Cunningham Iron Works Co., of South Boston, Mass., the firm which built the Holbrook stand-pipe, the following data have been secured:

The stand-pipe at Holbrook, Mass., is 30 ft. in diameter and 112 ft. in height. It was built in 1887, of refined iron of 50,000 lbs. T. S. The bottom is $\frac{7}{8}$ in. thick, flanged to the shell. The thicknesses of the shell plates are as follows:

First	15 ft.	....	$\frac{7}{8}$ in. thick
Next	20 "	....	$\frac{3}{4}$ " "
"	20 "	....	$\frac{5}{8}$ " "
"	20 "	....	$\frac{1}{2}$ " "
"	20 "	....	$\frac{3}{8}$ " "
"	17 "	....	$\frac{1}{4}$ " "

The angle at the top is $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{5}{8}$ in. The weight of the tank, including the rivets (5,000 lbs.), is 297,331 lbs.

While the Holbrook stand-pipe was not in the least injured by the slight lifting or rocking motion which it underwent, the incident seems to warrant the attention here given to it because of the possibility that the facts thus brought together may serve to throw some light upon the important question of wind action upon stand-pipes. Even though, as above stated, it was not at the time of the incident feared that the stand-pipe might actually be overturned, experience elsewhere has shown that the damage resulting from deficient or absent anchorage may not be confined to the foundation, but that the motion at the base, even when slight in amount, may greatly augment the vibrations of the thinner plates in the upper portion. The fact that no such damage resulted in the case under consideration would seem to be rather a compliment to the excellent quality of this particular structure than an approval of the practice of omitting anchorage upon the sole ground that the probability of the stand-pipe actually overturning may be somewhat remote.

The above data relative to the dimensions and weight of the stand-pipe in question are of an unusually definite character, and the figures bearing upon the maximum velocity of the wind are probably as reliable as it may ordinarily be possible to secure. In recognition of this fact, further attention will be directed to the above data in the discussion which will conclude Appendix I. It is sufficient here to state that the recorded maximum velocities are in this, as in other cases, wholly insufficient to account for the lifting of the structure, and the conclusion already stated at several points in the body of this record that the phenomenon must be assigned to the synchronous pulsations of the wind storm and the metal shell, seems to apply with equal force in this case.

References.—Journal of the New England Water-Works Association, 1893, p. 204. Engineering Record, Vol. XXVII., p. 216 (Feb. 11, 1893). Engineering News, Vol. XXIX., p. 243 (March 16, 1893). U. S. Monthly Weather Review, 1887, pp. 262, 294 and 316. Correspondence (in 1894) with Mr. Freeman C. Coffin, and Mr. Wm. Jackson, M. Am. Soc. C. E., City Engineer of Boston, and with Mr. Thos. Cunningham, of South Boston, Mass.

Hampton, Ia., March 26, 1893.

A fall of ice in the 10 × 110-ft. steel stand-pipe at Hampton, Ia., on March 26, 1893, resulted in damage of a striking character. The manhole connections were burst asunder, but fortunately the rupture did not extend beyond the one plate to which those connections were riveted. The water merely emptied itself through the orifice so formed and no further damage was sustained. The torn plate was replaced and the structure has since been in continuous service. The following account of the accident and of the conditions preceding and attending it has been obtained through the courtesy of Prof. A. Marston, M. Am. Soc. C. E., of Ames, and Mr. W. E. Hoxie, of Hampton, Ia.:

It had been extremely cold for several days. On the night preceding the accident the stand-pipe was pumped full, and it is believed that the mass of ice, consisting of a column or tube probably 40 ft. in

height, which had formed in the stand-pipe, was frozen fast to the sides at the top. The consumption of water during the night was such that the water level was not more than 30 or 35 ft. above the base on the morning in question. March 26, the date of the accident, was clear and was marked by a considerable thaw. By 9 a. m. the influence of the solar heat upon the metal shell of the stand-pipe served to loosen the hold of the mass of ice above so that it fell. The damage was confined to the plate on the southwest side, which contained the manhole. The manhole connections were torn loose and the hole was enlarged, allowing the water to empty without further damage. The character of the fracture indicated that the steel plate was of excellent quality, the edges of the hole resembling those of a bullet hole in a sheet of tin plate.

The dangers to be feared from the action of ice within a stand-pipe are set forth with renewed emphasis by the accident above described. The most important observation bearing upon this case is found in the indisputable evidence which it presents in favor of plate-metal having high ductility, for had the plate been brittle in character there is little doubt that the structure would have failed totally.

References.—Correspondence (in 1895) with Prof. A. Marston, M. Am. Soc. C. E., of Ames, and with Mr. W. E. Hoxie, of Hampton, Ia.

Dodge City, Kan., July 1, 1893.

The 12 × 100-ft. wrought iron stand-pipe built in 1886, at Dodge City, Kan., failed during a violent windstorm at 7:55 p. m., July 1, 1893. The following information relating to the structure and its failure has been obtained from Prof. E. C. Murphy, of Lawrence, Kan.:

The foundation of the stand-pipe, consisting of sandstone masonry, is on a hill 130 ft. above the Arkansas River. The plates were of iron, ⅛* in. in thickness at the bottom and ⅛* in. at the top, horizontal joints being single riveted, the vertical joints double riveted; the rivets were ¾ in. in diameter. There were six ¾-in. iron guy rods attached to the pipe 75 ft. from the foundation, and connected to masses of masonry 90 ft. distant from the foundation. Two of these were at the northeast point, two at the southeast, one at the northwest and one at the southwest point. There were also in addition to these two wire guys added five years after erection, one at the northeast, the other at the southeast point. There were stiffening angles at both the top and bottom of the pipe.

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* Probably ⅜ or 5-16 in.

The pipe leaned a little to the west, the two west guy rods being slack, while the four on the east side were taut. It was to correct or prevent further leaning that the two wire guys were added. The leaning was caused by the settling of the foundation on the west side. The opening for flushing, which was on the west side, leaked, saturating the ground on that side. It is not known when it began to leak. The pipe is said to have been full of water at the time it failed. The northwest guy rod broke 5 ft. from its anchor, at its union with the link; one of the northeast guy rods broke 20 ft. from its anchor at a link; the wire rope fastening at the top of the pipe failed.

The pipe failed in four places: (1) At the base, the first course tearing away from the bottom, leaving the latter in place; (2) between the 6th and 7th courses; (3) between the 11th and 12th courses; (4) a nearly vertical break between the 7th and 11th courses.

The pipe fell in a direction approximately south, the lower end now being at a distance of 12 ft. from the foundation.

The storm which led to the destruction of the stand-pipe is described as follows by the U. S. Meteorological Observer at Dodge City:

I observed the storm very closely. It came with great force in gusts from the north and northwest, but there was no whirl to it. The maximum velocity of the wind for five minutes was 54 miles per hour from the northwest. The extreme velocity (one mile in the shortest space of time) was 60 miles per hour. The maximum hourly velocity was only 30 miles. I think the wind blew much harder at the stand-pipe than at the observing station, because of the much exposed site of the former. Numerous chimneys and outbuildings about the city were blown down.

Unusual interest centers in the failure of the Dodge City stand-pipe, since it is the first total failure of a full tank here recorded in which the action of the wind was distinctly the cause. Careful consideration of the probable force exerted upon the cylinder by a 60-mile wind and of the weight of the full tank, even neglecting the additional stability afforded by the guys, gives no support whatever to the theory that the mass of water contained in the tank was actually lifted previous to the failure. In fact, the above-quoted statement by Professor Murphy, relative to the fracture about the base, and the undisturbed bottom indicates that the bedplate was held tightly in position by the hydrostatic pressure, supple-

mented by such adhesion as may have existed between the bottom of the tank and the mortar bed beneath it. It is, of course, certain that the guys attached to the north half of the stand-pipe must have given way before the metal shell could fall to the southward. This fact suggests the theory that the single northwest guy rod ruptured at a weld under the action of the violent gusts of wind, followed, perhaps, by the similar failure of a part or ail three of the northeast guys; then, with the unbalanced guys acting at a point 75 ft. from the base, probably much augmented by their whip-like motion, and combined with the vibrations of the metal shell, rupture took place near the base on the windward side.

In the light of a careful analysis of the conditions above outlined, allowing for a reasonable multiplication of energy due to the concurrence of gusts and vibrations, it may be remarked that the strains thus accounted for are not great enough to explain the fracture of sound plate metal with fair riveted work. The conclusion is therefore reached that a flaw existed, probably in the row of riveting about the base angle on the windward side. It seems worthy of remark that the structure probably would not have failed had not the unbalanced pull of the guys increased quite materially the tensile stress in the metal on the windward side. Thus it is seen that guys provided for the purpose of ensuring stability in the stand-pipe may, by the failure of a portion of them, prove a source of danger to the structure. In another place in this record reference has been made to the wisdom of using more than four holding-down bolts when stand-pipes are anchored at the base. This observation, it is seen, applies with like force to the use of guys.

References.—U. S. Monthly Weather Review, 1893, p. 204. Engineering News, Vol. XXXII., p. 257 (Sept. 27, 1894). Correspondence with Prof. E. C. Murphy, of Lawrence, Kan., and with the U. S. Meteorological Observer, Dodge City, Kan. (1894).

East Providence, R. I., Aug. 29, 1893.

As already stated in the original record, the then 40 × 120-ft. steel stand-pipe at East Providence, R. I., was lifted ¾ in. or more on its windward side during a gale which prevailed on Aug. 29, 1893, some nine days previous to the collapse of the upper portion of the stand-pipe. In connection with his description of the collapse of Sept. 7, Mr. J. J. Luther, Superintendent of the East Providence Fire District, thus refers to the earlier occurrence:

> In the gale of Aug. 29, 1893, it blew hard enough to raise the pipe on the windward side some 4 or 5 ins. It would spring in and out and rattle like a sheet of zinc when shaken. We pumped it full of water the next day, the first water that had been in except to test the bottom, and it leaked the least trifle.

Mr. Geo. H. Leland, Assistant to the Chief Engineer of the East Providence Water-Works, describes the same occurrence in Engineering News of Jan. 25, 1894, in connection with an account of the final failure of the stand-pipe, which took place on Jan. 19, 1894, as follows:

> On Aug. 29, 1893, a severe windstorm struck the stand-pipe, which was then completed to 120 ft., with the exception of two plates in the last or 24th course. During this storm the top swayed in and out like a large tree. The bottom on the windward side would lift from the foundation ½ to ¾ in. It was estimated that the wind at this time was blowing 60 miles per hour, but no harm was done to the stand-pipe at that time.

The estimate of the velocity of the wind above quoted is confirmed by copies of the record taken from the self-registering anemometer located at Providence, R. I., data from which have been obtained through the courtesy of Mr. J. Herbert Shedd, M. Am. Soc. C. E., City Engineer. Reference to the "U. S. Monthly Weather Review" shows that the storm of Aug. 29 was severe in character over a considerable area, as is shown by the following velocities:

New York city	54 miles per hour
New Haven, Conn.	57 " " "
New London, Conn.	57 " " "

An interesting and perhaps instructive observation may be reached by a comparison of the characteristics of the storm of Aug. 29, above described, with those of the storm of Sept. 7, which resulted in the collapse of the upper portion of the stand-pipe. The following statement, relating to the storm of the latter date, was obtained through the courtesy of Mr. Samuel M. Gray, M. Am. Soc. C. E., Chief Engineer of the East Providence Water-Works:

> The wind came in the form of a small cyclone, and only lasted 10 or 12 minutes, occurring about 7:50 p. m., when no one was present. In my opinion, it is quite probable that the stand-pipe did not lift from its base at this time, as the wind came on very suddenly.

Considering the difference in the nature of the two windstorms, that of Aug. 29 having been a gale, with frequent spurts of high velocity, but very short duration, while that of Sept. 7 was a "heavy blow," comparatively steady in force, followed by a single cyclonic burst of velocity lasting some ten minutes, there seems to be a sufficient explanation of the apparently anomalous occurrence of a lifting without collapse during the earlier storm, and a collapse without lifting during the latter. It is of interest in this connection to observe that with the two plates lacking in the 24th course on the earlier date, the ability to withstand a collapsing strain was doubtless less than on the latter when this deficiency had been supplied.

This reference to the East Providence stand-pipe for the third time in this record has been suggested by a similar incident at Holbrook, Mass., which has been described. Attention is again directed to the renewed discussion of the action of wind upon stand-pipes, which will be found at the conclusion of this Appendix. As will there be shown, and, as has been asserted in other and similar cases in these pages, the tilting of the East Providence stand-pipe may be accounted for only in the accumulation of energy by the concurrence of vi-

brations of the stand-pipe and gusts of the wind-storm.

References.—Engineering News, Vol. XXX., pp. 205, 237 (Sept. 14, 21, 1893). Engineering Record, Vol. XXVIII., p. 298 (Oct. 7, 1893). U. S. Monthly Weather Review, 1893, pp. 239, 266. Engineering News, Vol. XXXI., p. 76 (Jan. 25, 1894). Engineering Record, Vol. XXIX., p. 135 (Jan. 27, 1894). Correspondence with the City Engineer, Providence, R. I., and with the Chief Engineer of the East Providence Water-Works (1894).

Holdrege, Neb., April, 1894.

The 15 × 110-ft. steel stand-pipe, built in 1888, at Holdrege, Neb., was observed to be leaning toward the south soon after its completion, and the inequality in settlement continued until the departure of the top from its original position reached 54 ins. It leaked badly from the time it was first filled, and although this evil was somewhat reduced by periodical calking, it was not entirely remedied until April, 1894, when the tank was emptied for the purpose of restoring it to a vertical position. The latter was accomplished by means of two T-rails bolted about the tank near its base, serving as a bearing for five jackscrews. It was found that the most serious leakage resulted from a crack, which originated in the base angle on the south side and extended some 16 ins. upward into the first course of plates, and also from the breakage of the threaded collar which was riveted to the bedplate, and into which the inlet main was screwed.

The foundation of the stand-pipe is of good quality, and consists of arched sandstone masonry, with a footing of concrete 3 ft. in thickness. It must have settled as a unit, since no cracks were visible in the arch.

It is evident that the settlement was due to the saturation, and, perhaps, also to an inequality in the bearing power of the substratum. The break in the threaded collar seems to have resulted directly from the strains induced by the excessive settlement. That in the base angle and plate

was apparently traceable to flexural strains induced in the angle by the deterioration of the cement bed under the bottom about the edges, the action of frost and thaw being greatest on the south side.

Considering the grievous condition of the Holdredge stand-pipe at the time when the repairs were undertaken, there is much cause for congratulation in the fact that its total failure has not been recorded.

References.—Engineering News, Vol. XXXI., p. 431 (May 24, 1894). Correspondence (in 1894) with Mr. M. D. Case, of Atlanta, and Mr. E. A. Howard (the contractor who repaired the stand-pipe), of Holdrege, Neb.

Billingsport, N. J., May 15, 1894.

About May 15, 1894, the floor timbers under one of two wooden tanks, which were supported upon a timber framework, at Germania Park, near Billingsport, N. J., gave way, the entire structure being wrecked. Each tank was 13 × 13 ft. They were placed one above the other, the elevation of the higher tank being 60 ft. The floor system under the tanks, consisting of 6 × 12-in. hemlock joists, is said to have been too weak, although it is not stated whether the deficiency was in the spacing or the quality of the timbers.

Reference.—Correspondence with the Germania Park Co., Billingsport, N. J. (1894).

Bayshore, N. Y., May 20, 1894.

On May 20, 1894, at about 5 p. m., the flanged connection of the supply pipe to the 20 × 150-ft. stand-pipe at Bayshore, L. I., cracked during a severe gale of wind. The following communication relative to the accident from Mr. E. R. Smith, of Islip, L. I., appeared in Engineering News of May 24, 1894:

The shank of the supply pipe cracked from the flange through the lower semi-circumference, at the end which is bolted to the stand-pipe, as shown in the accompanying sketch (Fig. 28). The stand-pipe was nearly full at the time of the accident, and the break was undoubtedly caused by the vibration of the stand-

pipe, due to the high wind blowing a gale from the east, the supply pipe being at the opposite side. The stand-pipe was built in 1890.

The following additional facts have been obtained by personal communication from Mr. Smith:

The foundation of the stand-pipe is of grouted brick masonry, the depth of which is 3½ ft., the diameters being 20 and 23 ft. at the top and bottom, respectively. The foundation rests upon a stratum of sharp quartz sand containing a little gravel. This stratum extends to an indefinite depth, and it is regarded locally as practically incompressible, the slight settlement which does take place being as a rule perfectly uniform. The

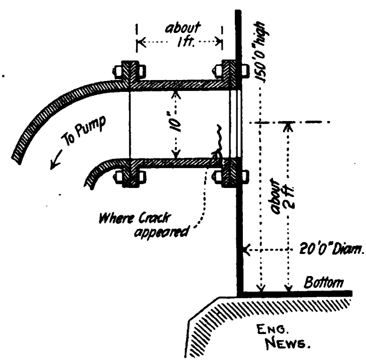

FIG. 28. BREAK IN SUPPLY MAIN TO STAND-PIPE AT BAYSHORE, L. I.

stand-pipe is located on low ground, and springs are encountered at a depth of about 2 ft.

The inlet pipe being on the W. S. W. side of the stand-pipe, is little affected by any slight movement which may take place under the action of the heaviest winds in that locality, they being most common in the northwest and southeast. The storm of May 20, 1894, from the east and northeast, was the heaviest known for years from that direction.

Rope guys had been secured to eyes located somewhat more than half-way up the sides of the stand-pipe, but they were never secured at their lower ends, and some months ago when the stand-pipe was painted they were taken down. No anchorage whatever at the base was provided.

The U. S. Weather Bureau records show that the maximum velocity attained by the wind during

the storm in question was 34 miles per hour at New York city between the hours of 5 and 6 p. m. on the above-mentioned date, the same velocity having been observed a few hours eariler at New Haven, Conn.

While the opinion above quoted, that "the break was undoubtedly caused by the vibration of the stand-pipe due to the high winds," is confirmed by a consideration of all attending circumstances, it is important to observe that the force required to stir bodily the "nearly full" 20 × 150-ft. tank (weighing not far from 3,000,000 lbs.) was far in excess of that which could have been exerted by a storm having a maximum velocity no greater than was recorded in that locality during the same storm; and, furthermore, the assertion just made is true even of the greatest wind pressures yet reliably recorded in any locality. Such being the case, it becomes necessary to seek an explanation through another channel.

It is stated that the lower elbow of the downward turn to the supply pipe was entirely clear of the brick masonry of the foundation, so that whatever settlement had taken place during the period of about four years from the time of completion of the stand-pipe must have had the effect of developing in the rigidly-connected flanged castings a condition of flexural strain. The severity of these strains would depend upon both the rigidity of the connections and also the hardness of the stratum upon which the adjoining supply pipe rested, and they would seem to have been most severe at the point of fracture shown in Fig. 28.

Taking into account all known conditions, it would seem that because of the unusually gusty character of the gale in question, vibrations were set up in the less rigid upper portion of the nearly full stand-pipe, and that these vibrations, probably growing sharper and sharper under the concurrent action of a series of spurts of the storm, were transmitted through the thicker plates be-

low to the rigidly connected and previously overstrained supply pipe. It is scarcely necessary to add that this theory is confirmed by the characteristic tendency of cast iron to fail suddenly under slight impact when suffering internal strain, and it also seems to be in full accord with the position and extent of the crack, as shown by Fig. 28.

The most striking lesson taught by the occurrence above described is the need of having such a degree of flexibility in connections of this class as to avoid strains of a severe kind under the action of vibrations or slight movements in the standpipe. It is stated by Mr. Smith that this need has been recognized, and that provision has been made for it by the use of a flexible connection in making the repairs.

References.—Engineering News, Vol. XXXI., p. 432 (May 24, 1894). Correspondence with Mr. E. R. Smith, of Islip, L. I., and with the chief of U. S. Weather Bureau, Washington, D. C. (1894).

Pana, Ill., June, 1894.

The 20 × 100-ft. stand-pipe, which was completed and put into service at Pana, Ill., in June, 1894, was observed to be out of plumb shortly after it had been put into use. An examination at the time revealed no defect either in the foundation or elsewhere in the structure. The stand-pipe was found to be 5 ins. out of plumb. The above information was obtained from Vorhees & Witmer, Engineers of the Pana Water-Works, who have also given the following details of the foundation and explanation of the trouble:

The foundation is a monolith of Portland cement concrete extending eight feet below the surface of the ground, where it rests on a compact, gravelly clay, so hard that it required picks to remove it.

We cannot offer any good explanation of the trouble except that when the stand-pipe was first filled the inlet pipe broke, letting the water out. Although it drained off quite rapidly through a trench, the water may have softened the earth under that side of the foundation (which up to that time had been exceedingly dry) and rendered it more compressible. It is toward this side that the stand-pipe leans. It would require a settlement of only 1 in. on that side of the foundation, if the other side remained firm, to divert

the top of the pipe 5 ins. The weight on the soil under the foundation, including water, steel and foundation, is 1.44 tons per sq. ft., which is certainly not severe for such soil as that under this foundation.

The stand-pipe has remained in uninterrupted service. It is stated that little apprehension is felt as to the safety of the structure, as it is believed that the foundation has settled intact toward the one side.

References.—Correspondence with the designing and constructing engineers, Pana Water-Works (1895).

Newport, Ark., July 9, 1894.

On July 9, 1894, the elevated wooden tank of the Newport (Ark) Water Co. fell to the ground, a total wreck. This tank was a duplicate of that which failed at Newport by the bursting of a hoop in May, 1887, as described in the original record. The diameter of the tank was 24 ft., and the staves were 20 ft. long by 3 ins. thick. The hoops were 20 in number, ranging from 3½ to 7 ins. wide, and having a thickness of 3-16 in. throughout. The diameter of the draw-bolts varied from ⅞ to 1¼ ins. No information as to the supporting tower is given, except that its height was 100 ft. and that it was built of timber.

The cause of the accident is not stated, but there is little doubt that it was due to the deterioration of the supporting frame. Early in 1893 the necessity of renewing or reinforcing the frame was recognized, and about a year previous to the failure a proposal to replace the wooden frame by a steel trestle tower, with the view to a subsequent renewal of the tank, when required, was received and seriously considered. It seems, however, that the water company, for some reason, deferred action in the matter too long, resulting in the serious consequences above recorded. It is stated that the third structure will consist of a steel tank of the same diameter and height as the former wooden tanks, and that the support will be a brick tower 100 ft. high.

References.—The Little Rock (Ark.) Gazette (Nov. 10,

1894). Correspondence (in 1893) with the Newport Water Co.

Salem, So. Dak., July 13, 1894.

A 16 × 24-ft. elevated wooden tank, connected with the water-works at Salem, So. Dak., failed on July 13, 1894. The following particulars regarding the tank and its failure were contributed by Mr. M. A. Blackburn, Engineer and Superintendent:

The foundation consisted of six masonry piers, each 11 ft. long, 18 ins. thick at the top, 3 ft. thick at the bottom, and 3 ft. deep. On these piers were laid 12 × 14-in. timbers 10 ft. in length, upon which stood twelve 12 × 12-in. vertical posts 20 ft. high. These were braced by 6-in. timbers, and tied by ¾-in. iron rods. The posts were capped by 12 × 12-in. timbers, two 28 ft. and two 16 ft. in length, which in turn supported 2 × 14-in. joists, 12 ins. c. to c. The joists were not bridged, but were doubled beneath the central part of the tank. It was these joists that crushed and lopped over, causing the hoops of the tank to burst. A double floor of 1-in. boards was nailed to the joists, and upon this floor 4 × 6-in. "chime-posts" were placed to support the tank bottom. As the stone foundation, trestle-tower and cap timbers were level and plumb after the wreck, it is hardly possible that any defect in those respects caused the trouble. The tank was a regular 16 × 24-ft. structure.

Two eye-witnesses, one the assistant engineer, say they heard a noise as though some one was pounding on the hoops. On looking up they saw the tank settling to one side slightly. It then settled down, and at the same instant the hoops began bursting from the bottom and ripped upwards. The staves and water went in all directions, and some pieces of hoop and staves landed 150 ft. away. Fortunately no one was hurt. The pump house directly at the side of the tank was completely demolished, but the machinery was only slightly damaged. In rebuilding the tank, 3 × 10 and 10 × 10-in. joists, spaced 8 ins. c. to c., were used.

Although the supporting frame did not give way, the fact that the tank itself was demolished was taken to be sufficient reason to class the accident as a total failure in the final discussion.

References.—Engineering News, Vol. XXXII., pp. 63, 114 (July 26, Aug. 9, 1894).

Pelican Sawmill, La., Sept. 20, 1894.

On Sept. 20, 1894, a timber trestle, built to support two water tanks of 50,000 gallons capacity, at the Pelican Sawmill, New Orleans, gave way, and a

man engaged in painting the tanks was killed. The tower was 50 ft. high, built of timber 12 x 14 ins., and the tanks are said to have contained only 15,000 gallons of water at the time of the accident.

An attempt to secure additional information relative to the causes leading to the failure was unsuccessful.

References.—Engineering News, Vol. XXXII., p. 243 (Sept. 27, 1894).

Anthony, Kan., Jan. 20, 1895.

The 12 x 150-ft. wrought iron stand-pipe at Anthony, Kan., was wrecked by a severe windstorm during the night of Jan. 20, 1895. Pumping had ceased some six hours previous, and there was about 140 ft. of water in the stand-pipe at the time of the accident. The wind blew from the northwest, and the structure fell to the southward. The first course of plates was torn entirely loose from the bedplate, the water escaping at the base without serious damage to surrounding property. The metal shell was flattened out and was broken into three pieces by the force of the fall, as may be seen in the view of the ruins, Fig. 29.

The stand-pipe was secured by ten guys, arranged in two sets of five each in alternation, attached to collars or rims at 12 and 42 ft., respectively, from the top. The lower ends of the guys were fastened to masonry anchors. No data were secured in relation to the thicknesses of the plates nor the details of the riveting.

In seeking a cause for this accident, the evident similarity between it and the Dodge City failure in all essential features leads at once to the belief that the same explanation applies to both. The theory already assigned for the Dodge City failure assumed the rupture of the windward guy or guys, so that the remaining guys acted to augment the strain at the base on the windward side of the stand-pipe, where a flaw prob-

FIG. 29. VIEW OF STAND PIPE RUINS AT ANTHONY, KAN., LOOKING SOUTHEAST.

ably existed. While it must be granted that the increased number of guys at Anthony tends somewhat to discredit the theory as stated, it is here adopted as being the most plausible. It is very certain that the wind could not have overturned the nearly full tank weighing not far from 1,000,000 lbs. An inspection of the view, Fig. 29, indicates that the initial fracture occurred on the windward side in the line of single riveting at the edge of the bedplate.

In the absence of holding-down bolts or other anchorage at the base of the stand-pipe, it is obvious that the rivets connecting the bed-plate to the base angle would be thrown in tension on the windward side in the event of the failure of the windward guys during a severe windstorm, assuming that the combined wind and guy moment exceed the gravity moment of the tank itself. The contained water serves to hold the bed-plate tightly to the foundation, and also has the effect to steady the metal shell as a whole under the action of the gusts of the storm. It is learned that the Anthony stand-pipe had leaked about the base. It is very certain that poor workmanship would tend to increase the danger of a failure in the manner above detailed

It is stated that the upper rim or collar to which the guys were attached was first carried away by the wind, but as is often the case in a wreck, it is manifestly difficult to distinguish between cause and effect, so that the ruptured collar may have been a result rather than a cause of the accident. Further consideration will be given to this and to the two related failures at Caldwell and Dodge City, Kan., in the discussion at the conclusion of this Appendix.

The following information relating to the storm which led to the Anthony failure was obtained through the courtesy of the local observers of the U. S. Weather Bureau, at the nearest stations having self-registering anemometers:

Observing station.	Distance (miles) and direction from Anthony.	Velocity (miles per hour) and direction of wind.
Wichita, Kan...........	50 n.e.	41 n.w.
Dodge City, Kan........	115 w.n.w.	38 s.w.
Oklahoma, Okla.........	120 s.s.e.	30 n.w.

References.—Engineering News, Vol. XXXIII., p 97 (Feb. 14, 1895). The Anthony (Kan.) "Republican," Jan 25, 1895. Correspondence with the Superintendent of the Anthony Water-Works, and with U. S. Weather Bureau Observers, as noted above (1895).

Thibodaux, La., March 29, 1895.

On March 29, 1895, the 12 × 115-ft. steel stand-pipe at Thibodaux, La., while being filled for the first time, was observed to be settling unequally when about two-thirds full. It was emptied immediately for the purpose of investigating the cause of the trouble. The results of the investigation have not been learned.*

The thickness of the plates ranged from ⅝ in. at the base to ⅜ in. at the top of the stand-pipe. The foundation consisted of concrete and brick-work 8 ft. in thickness.

References.—New Orleans (La.), "Times-Democrat," March 27, 30, 1895.

Griswold, Ia., April 13, 1895.

On April 13, 1895, the 10 × 100-ft. stand-pipe at Griswold, Ia., when filled for the first time began to settle to one side, the top of the structure moving 2 or 3 ft. out of plumb. Owing to lack of time, further information could not be obtained before going to press.

References.—The Atlantic (Ia.) "Telegraph," April 17, 1895.

Discussion.

The number of cases included in this Appendix is hardly such as to demand a tabulated classifica-

* A press despatch to the New Orleans "Picayune," dated April 20, states: "The tower of the water-works plant has been filled to its full capacity and now stands perfectly plumb."

tion. The following brief summary will serve the purposes of the discussion:

(1) Chicago, Ill., 1854.
Leaning brick tower. No damage.

(2) Erie, Pa., 1872.
Buoyant action of ice cylinder. Slight damage.

(3) Wilmington, N. C., 1881.
No bedplate. No damage.

(4) Holbrook, Mass., October, 1887.
Tilted slightly by windstorm. No damage.

(5) Hampton, Ia., March 26, 1893.
Manhole connections burst out by falling ice.

(6) Dodge City, Kan., July 1, 1893.
Wrecked during severe windstorm. Total failure.

(7) East Providence, R. I., Aug. 29, 1893.
Tilted slightly by gale. No damage.

(8) Holdrege, Neb., April, 1894.
Leaked; leaned; base angle, first course plate and inlet pipe collar cracked. Slight damage.

(9) Billingsport, N. J., May 15, 1894.
Elevated wooden tanks; floor system gave way. Total failure.

(10) Bayshore, N. Y., May 20, 1894.
Shank of inlet pipe cracked during gale. Slight damage.

(11) Pana, Ill., June, 1894.
Leaned. No damage.

(12) Newport, Ark., July 9, 1894.
Elevated wooden tank; frame gave way. Total failure.

(13) Salem, S. D., July 13, 1894.
Elevated wooden tank; floor system gave way. Total failure.

(14) Pelican Sawmill, La., Sept. 20, 1894.
Elevated wooden tank; frame gave way. Total failure.

(15) Anthony, Kan., Jan. 21, 1895.
Wrecked by wind. Total failure.

(16) Thibodaux, La., March 29, 1895.
Leaned. No damage.

(17) Griswold, Ia., April 13, 1895.

Leaned. No damage reported.

A review of the foregoing matter suggests several noteworthy observations, some of which were brought out in the original record. Of the new points here developed, reference may be made to the possibility of damage to the base angle by the deterioration of the mortar bed beneath the bed-plate about the edges. Another matter not encountered in the original record is the need of providing against strains in the inlet pipe at the point where it is connected with the tank or its foundation. This matter involves consideration of the settlement of the foundation itself, and the two are closely concerned in the importance of providing efficient drainage for the stand-pipe site. Still another related matter is the proper construction and maintenance of the seams, and this again bears upon the necessity of frequent attention to the preservation of the exposed metal surfaces from corrosive influences.

In connection with the description of the accident to the Stevens Point, Wis., stand-pipe in the original record, an account was given of experience with ice at that place along several lines, among which reference was made to the protrusion of the great tube of ice above the top of the stand-pipe. It is seen that the incident at Erie, Pa., described in this Appendix, is a similar illustration of the possible buoyant action of ice in stand-pipes, and it is very evident that the danger to be feared from such an occurrence is by no means limited to the upward force. That force should have critical consideration when the use of a roof is contemplated, but it is important in all cases to recognize the imminent danger that may result from so enormous a weight becoming fastened in its elevated position, and subsequently falling when the stage of the water is low. Valuable corroborative proof that extreme caution is demanded during periods of alternating thaw and freeze is found in the

accident at Hampton, Ia. This danger seems to be greatest during the month of March. In this connection it seems timely to refer to the fact that the danger from such accidents may be even greater in a locality where icy winters are the exception rather than the rule, for the reason that those responsible for the safety of the stand-pipe are less apt to be on the alert than where ice usually forms in excessive quantities. The subject of ice action in stand-pipes was quite fully considered at the conclusion of the original record, but the importance of the subject warrants further reference to it.

Referring to the omission of a metal bottom in the construction of a stand-pipe, it should be stated that such omission is not of itself alone to be condemned, as is conclusively proven by several stand-pipes which have been so built with entirely satisfactory results. However, where such a plan is adopted, it is clearly incumbent upon the designer and builder to provide the equivalent of the bedplate in tightness and safety by the use of correctly designed and executed calking grooves and shoes.

The alarming frequency with which failures of elevated wooden tanks have taken place recently possibly warrants the inference that a financial policy, which has prompted the selection of a supposedly cheap structure, has been allowed to obscure the principles of genuine economy so far as to violate the essentials of safe construction. The recognition of the legitimate field of the temporary structure, and its unquestioned merits under certain conditions, does not, under any circumstances whatever, warrant a sacrifice of the element of safety.

Of the three agencies—water, ice and wind—which, it has been seen, may endanger the stand-pipe, less seems to be known of the action of the last named than of the other two. This fact warrants the introduction of any data which may serve to throw

TABLE XI.—Data Relative to Stand-Pipes Which Have Been Lifted More or Less On the Windward Side During Violent Windstorms.

Item.	Holbrook, Mass., Oct., '87.	E. Providence, R.I., Aug. 29, '93.	Kankakee, Ill., Oct. 14, '86.	Plattsmouth, Neb., Apr. 9, '87.
(a) Diameter of stand-pipe, ft.	30	40	20	25
(b) Height " " "	112	120	124	80
(c) Projected area of cylinder, sq. ft.	3,360	4,800	2,480	2,000
(d) Approximate weight of tank, lbs., total	300,000	500,000	140,000	100,000
(e) Approximate horizontal force, acting midway of height, required just to balance the force of gravity, lbs., total	80,360	166,670	22,580	31,250
(f) Average unit pressure per projected sq. ft. of the cylindrical surface, corresponding to (e), lbs.	23.9	34.7	9.1	15.6
(g) Maximum velocity of the wind (as it would probably have been indicated by an anemom. located at stand-pipe), miles per hour.	50	60	40	40
(h) Corrected velocity corresponding to (g), miles per hour	(41)	(48)	(33)	(33)
(i) Static pressure, per sq. ft. of flat surface, corresponding to the velocities in (h), as computed by formula (l), lbs.	6.7	9.2	4.4	4.4
(j) Resulting total static pressure on stand-pipe in the direction of the wind, the resistance of the cylindrical surface being assumed at one-half that of a normal flat surface having an area equal to the projection of the cylinder, lbs., total	11,250	22,080	5,460	4,400
(k) Average unit pressure per projected sq. ft. of the cylindrical surface, corresponding to (j) (equal to one-half of (i)), lbs.	3.4	4.6	2.2	2.2
(l) Ratio of (e) to (j), or of (f) to (k).	7.1	7.5	4.1	7.1
(m) Effect produced by windstorm on the stand-pipe	Slightly lifted.	Slightly lifted.	Rocked, collapsed, overturned.	Rocked, collapsed.
			—Anchorage failed.—	

light upon this complex question, particularly since there seems to be a division of opinion among engineers as to the necessity of providing special anchorage for stand-pipes.

In discussing Table V., of the original record, in which were grouped the "wind" accidents, the assertion was made that little reliance can be placed on gaged wind velocities.. That conclusion was reached only after repeated and unsuccessful attempts to reconcile computed pressures and observed phenomena in the cases investigated. The collection and consideration of other data of an exceptionally complete and reliable character throw new light upon the subject and prompt a a qualification of the assertion above referred to.

It is the purpose of Table XI. to determine the possible influence of concurrent vibration and impact of the wind upon stand-pipes. In this table are grouped "data relative to stand-pipes which have been lifted more or less on the windward side during violent windstorms." In addition to the two cases, Holbrook and East Providence, given in this Appendix, the table embodies data relating to the Kankakee and Plattsmouth accidents from the original record. In each of the four cases the tank was entirely empty at the time of the accident or incident. In the first two cases no anchorage had been provided, because of the belief that none was needed. Holding-down bolts were provided in the other two, but owing to the deficient connection with the foundation in the case of Kankakee, and a defective bolt at Plattsmouth, the anchorage failed in both cases.

Except in the matter of diameter and heights, no attempt at exactness has been made in the figures contained in Table XI. Thus, in fixing the weights, that of the Holbrook stand-pipe is taken at 300,000 lbs., although its actual weight, as stated in the description of that incident, is somewhat less than this amount. The weights of the other three are also approximate, having been com-

puted. Item (e) gives the horizontal static force which, acting midway of the height, would be required just to balance the weight of the empty tank, neglecting consideration of anchorage at the base, or adhesion of the bedplate to the foundation. The next item, (f), presents the mean pressure per projected square foot, found by the division of (e) by (c), the purpose of which will directly appear.

In estimating the velocities of the wind, the nearest anemometric records during the same storm have been utilized. These assumed velocities are, of course, subject to such errors as may result from local variations of intensity in the storm, but they are as nearly correct as it may ordinarily be possible to secure, and, besides, it will be seen that they may be materially in error without nullifying the results and conclusions reached in the inquiry. The velocities assumed for Holbrook and East Providence are, it is believed, justified in the descriptions of those cases. In the case of Kankakee the assumed velocity is based upon observed velocities of 34 and 36 miles per hour at Springfield and Chicago, Ill., respectively. The velocity taken for Plattsmouth was fixed with respect to an observed velocity of 36 miles per hour at Omaha, 20 miles distant. It should be stated that much higher values were assigned for these two cases in Table V., in an attempt to make the velocities more nearly consistent with the observed effect of the storm. The selection of even ten-mile values is in keeping with the approximate character of the table.

The "corrected velocities" given under item (h) were obtained from the reduction table used by the U. S. Weather Bureau in connection with the records obtained from the standard government anemometer.*

* Following is an extract from the reduction table for even ten-mile velocities, taken from a circular issued by the U. S. Weather Bureau:

In item (j) the pressure of the wind on the cylindrical surface is taken at one-half that on a normal flat surface, having an area equal to that of the diametral plane of the cylinder. This assumption accords with the recommendations of Rankine (Applied Mechanics, p. 240), and is supported by the results of recent experiments by Professor Kernot, of the University of Melbourne.** It should be stated,

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Velocity indicated by standard U. S. Weather Bureau anemometer (velocity in miles per hour):

0.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0

Corresponding corrected velocity:

0.0	9.6	17.8	25.7	33.3	40.8	48.0	55.2	62.2	69.2

The pressures stated in item (i) were determined by the substitution of the "corrected velocities" in the following formula:

$$P = 0.0040\ V^2. \qquad (1)$$

in which P = pressure of wind in lbs. per sq. ft. and V = velocity of wind in miles per hour.

In computing velocities corresponding to given pressures, the following expression derived from (1) has been found convenient:

$$V = 1/2\ (1{,}000\ P)^{1/2} \qquad (2)$$

Equation (1) differs from the old Smeaton rule for wind pressures only in the coefficient, the earlier value being 0.005. The form of this expression has been criticised by some authorities, but its proper use seems to be entirely consistent, at least until it is replaced by a more trustworthy expression. The value of the coefficient was determined experimentally, but there is much need of more extended experiments which will include larger surfaces and higher velocities. In presenting this formula, the circular above referred to states that the "corrected velocities" are to be used. and in commenting upon both the reduction and pressure formulas, it is explained that while they "give results more nearly correct than before obtained, yet, owing to the great difficulty of making accurate experiments at high velocities, these adopted values may ultimately need comparatively small corrections."

The formula deduced by Prof. Langley, of the Smithsonian Institution ("Experiments in Aerodynamics," 1891), has the same form as (1), and is probably the most trustworthy in use. The value of the coefficient is 0.0036 for a barometric pressure of about 29 ins. and temperature of 50° F. At a freezing temperature and with a normal barometer the Langley coefficient is slightly less than that used in equation (1).

**Recent experiments by Irminger, a Danish engineer (Engineering News, Vol. XXXIII., p. 110, Feb. 14, 1895), fix this ratio at 0.57. Bixby, an American authority (Engineering News, Vol. XXXIII., p. 183, March 14, 1895), adopts a value of 0.60 for use in bridge design. The use here of the somewhat smaller ratio of 0.50 does not affect the character of the conclusions reached by means of Table XI.

also, that this is the usual assumption made in practice, although some use a-value as high as two-thirds. Item (k), corresponding to (f), is obtained in an obvious manner.

The real purpose of Table XI. is fulfilled in item (l), in which are expressed what may be termed the ratios of "force exerted" to "force apparently available." That this ratio should exceed four in one case and seven in the other three is without question a startling fact. The close agreement in the ratios determined in three of the cases is not an essential feature of the investigation, inasmuch as precision was not attempted in fixing the velocities. However, this agreement of results may be justly taken as a proof of the general correctness of the basis of the assumed data. It is of interest to observe that overturning took place only in the case having a low ratio, and it is seen that this structure also had the lowest factor of stability. Careful consideration of the methods by which these ratios were obtained in connection with the information contained in the last item, (m) of the table, leads to the belief that the ratio in the case of Kankakee was probably considerably greater just previous to the failure of the anchorage. Since collapse took place after the failure of the anchorage in the last two cases, the increased pressure of the wind, due to the formation of the flattened top, has not been considered in the above investigation.

The explanation of the paradox indicated by the results in Table XI. is of a twofold character. First, and probably most important, is the element of coincident vibrations of the structure and gusts of the wind, to which reference has been made in various connections in both the original and supplementary records. The other agency to which reference is above made is the prevalence in the storm of bursts of velocity, which were so momentary in their action as to find no recognition by the comparatively sluggish anemometer.

That such is true even of winds of low velocity has been shown by recent experiments, in which auxiliary anemometers of an exceedingly delicate character were used. Thus, for example, it was found that with a wind indicating a velocity of but 20 miles per hour by the standard anemometer, registering only every mile of travel, the more sensitive instrument showed momentary spurts as high as 60 miles per hour. Simultaneous observations of velocities and pressures made on the summit of Mt. Washington in 1890 developed a similar fact, as indicated by fluctuations in the pressure diagram. These experiments and the deduction of the coefficient of formula (1) were described in the valuable contribution on "Wind Pressures and the Measurement of Wind Velocities," by Prof. C. F. Marvin, which appeared in Engineering News of Dec. 13, 1890.* The concluding paragraph of the paper has a direct bearing upon the subject of impact of wind, and is as follows:

> In estimating the strains to which engineering structures may be subjected by winds, the maximum pressures are, of course, the most important. The above formula gives a mean pressure corresponding to a mean wind velocity. It is important to note that momentary pressures as much as 35% in excess of the above mean pressure may continually occur and recur. If their rate of occurrence be at all synchronous with

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* Since this reference to the Marvin experiments was put in type, a very elaborate and valuable monograph on "Wind Pressures in Engineering Construction," by Capt. W. H. Bixby, M. Am. Soc. C. E., has appeared (Engineering News, Vol. XXXIII., pp. 175-184, March 14, 1895). Careful study of the work referred to confirms the belief that the premises upon which Table XI. and the accompanying discussion and conclusions are based are entirely sound, and that the methods adopted in the investigation accord with good current practice. The following quotation from the Bixby monograph (paragraph 126) is of interest in connection with the statement above from the Marvin article:

"All high-wind velocities . . . may be subject to repeated oscillations of from 30 to 40% each way from the average at half-minute intervals for several minutes, and sometimes even to an increase of 60% for nearly a whole minute."

the natural time of vibration of the structure or any part thereof, remarkable results may follow.

The facts and statement above quoted, undeniably find strong confirmation in item (l) of Table XI. In concluding this discussion of the action of wind upon stand-pipes, it seems proper again to comment upon the belief which seems to prevail in some localities, that stand-pipes do not ordinarily require other anchorage than is afforded by the dead weight of the empty tank. Even admitting that the probability of entire destruction of the stand-pipe by the action of wind may be exceedingly remote, the relatively small cost of providing against an emergency, which may occur in the life of almost every stand-pipe, seems to remove all defense of the omission of such provision.

An effort was made to include in the above inquiry the case of the Dodge City stand-pipe, but it was found impracticable to fix a definite basis for the effect of the guys. In fact, as already stated in the description of that accident, and the precisely similar one at Anthony, Kan., it seems very certain that the stand-pipes referred to would not have failed at all had not the guy action become unsymmetrical by the failure of the windward guys. Furthermore, it seems altogether plausible that the overturning of the guyed stand-pipe at Caldwell, Kan., in 1886, while empty during construction, described in the original record, was due to the same cause. The dimensions of these three guyed structures were quite similar, being 12 × 150, 12 × 100 and 12½ × 150 ft., respectively. Perhaps the most interesting and also significant relation between them, however, is found in their geographical position, the three being on an almost exact west-northwest line, the distance from Dodge City to Anthony being about 115 miles, and from Anthony to Caldwell about 25 miles. These accidents raise the question of the propriety of depending upon guy anchorage alone, particularly in the case of the type of tall and slender

stand-pipes that prevails in many towns of small size in the Western prairie states. It is believed to be a wiser plan, and the one toward which a number of careful designers seem to be tending, to secure a widened base by means of properly designed brackets, and to stiffen the upper portions of the structure so that guys are unnecessary.

In conclusion, it seems desirable to summarize briefly the foregoing records. A total of 45 cases have been described, 28 of which were in the original record, and the remaining 17 in this Appendix. Of these, 23 were total failures, the others ranging from cases of serious damage to seemingly unimportant incidents. Special interest attaches to the total failures. These are reclassified in Table XII.

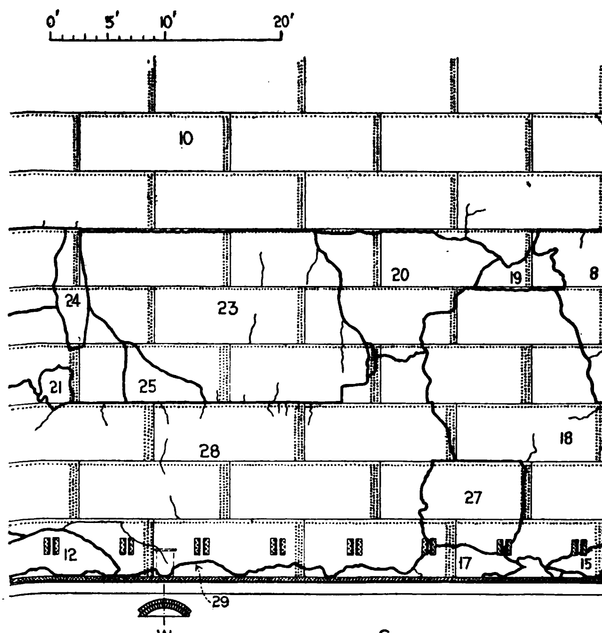
TABLE XII.—Special Classification with Reference to Date of Construction and Kind of Metal in the Cases of Thirteen Stand-Pipes Whose Total Failures were Due to or Accompanied by Plate Fracture.

Year built.	Steel.	Wrought iron
1859	.	1
1868	.	1
1881	1	.
1886	2	2
1887	2	.
1889	1	.
1890	2	.
1893	1	.
Total, 13	9	4

Of the 23 cases of total failure, two were due to defective masonry or foundation, seven were elevated wooden tanks, and in one case the stand-pipe was demolished by overturning. The remaining 13 cases of total failure either originated in, or were accompanied by, plate fracture. For this reason they are of special interest in contrasting the two metals used in their construction. Table XII. presents a classification of these cases, which

may not be entirely without value in considering the relation between quality of plate metal and period of development. Three of these 13 failures occurred previous to the year 1886, one each during the years 1886, 1887, 1890, 1891 and 1895, three in 1893 and two in 1894. Tracing existing conditions and probable cause, it is found that 6 of the 13 total failures occurred under simple hydrostatic pressure, two under wind action and five in the presence of ice. Of the last-named cases four have taken place since 1890. Referring to the 10 cases of total failure which are not included in Table XII., it will be seen that in no case has the date, either of construction or failure, fallen prior to the year 1885.

There is no evidence that stand-pipe accidents are on the decrease, and with the number of stand-pipes continually increasing, it seems very certain that accidents of more or less severity will continue to occur. Their frequency, in the future as in the past, will in a degree depend upon the severity of meteorological conditions, but the fact cannot with reason be disputed that a very considerable diminution in the number of such accidents might be effected by proper care on the part of those who are directly responsible for the design, construction and also the subsequent use of the stand-pipe.



ver Courses of Stand-Pipe, Showing Original Positior of Fragm ents.

APPENDIX II.

ANOTHER ACCOUNT OF THE PEORIA FAILURE.

(The publishers, with the consent of the author, have deemed it advisable to include here some drawings of the Peoria wreck, with a letter accompanying them, sent to the Editor of Engineering News only a few days after the failure by Mr. Dabney H. Maury, Jr., Superintendent of the Peoria Water Co. After sending the matter, Mr. Maury requested that it be withheld from publication for a time, the company's property being in the hands of the United States Court, under which he acted as superintendent. The letter and drawings were accordingly put aside. As this book was about to go to press, the above matter came to the attention of the publishers, who thought it a pity that such interesting and valuable drawings and comments should remain hidden away. Inquiry showed that there was no longer any objection to making the letter and illustrations public. As Professor Pence had not seen the matter, and the book was too far advanced to admit insertion in its proper place anyway, it was decided to present it in the form of an Appendix, and it is printed below for the first time.—Publishers.)

I read with interest Professor Pence's report on the failure of the Peoria stand-pipe, as published in Engineering News of April 5, 1894. In what follows I shall confine myself to a simple statement of the facts, as I know them, without entering into any theory of the cause of the failure.

I was present at the scene of the wreck a few moments after the stand-pipe fell, and feel confident, from my own observation, as well as from credible reports of persons present, that the velocity of the

wind was not more than 20 miles per hour. To a man handling a bucket and brush at the top of a 36-ft. ladder, resting against a smooth, round surface, a light breeze will seem a strong wind.

I send you herewith two drawings which I made from actual measurements on the ground. No. 1 (Fig. 30) is a map of the ground after the wreck, showing the position of the fragments of the fallen tower, and of the damaged buildings, the former being indicated by numbers, the latter by letters. Drawing No. 2 (Fig. 31) is a development of the eight lower courses of the stand-pipe, showing the position each fragment occupied in it before it burst. The part of the tower above the eighth course, being practically intact, is not shown in this drawing. The few vacant spaces shown on this development were occupied by pieces which could not be found, and which are doubtless buried under some of the damaged houses or the larger fragments of the tower.

The rupture started on the line AAA, Fig. 31, just a few inches to the east of north, the cardinal points being indicated by the letters E., N., W., S., at the bottom of the developed sheet. All the pieces to the west of A were whipped around to the west of south; the large sheet, No. 28, wrecking and burying itself under the dwelling E, shown in Fig. 30. Sheet 31 was found 245 ft. to the southwest of the center of the tower. The pieces to the east of A went to the northeast, east and southeast.

It is difficult to decide just what caused the main portion of the tower to fall to the east, but there is no doubt in my mind that as it dropped it cut the gashes seen near the north edge of the base of the tower, and the direction of its fall thereafter would seem to me to depend more upon the position at the instant of contact of the projecting edges that cut the gashes, with regard to the center of gravity of the whole mass, than upon the wind or any other cause. Once resting on the base, and leaning, the reaction of such water as remained in the pipe would help throw it further in the direction towards which it leaned, and could, with the natural rebound of the sheet metal, easily land it in its present position. The gashes in the heavy plates which form the base of the tower are cut clean through the steel and several inches down into the concrete below it, showing that

the force which cut them must have been enormous. The small fragment of metal still sticking in one of these gashes is shown by its line of single rivet holes and its beveled edge to be the top edge of some sheet, and, by its thickness, to belong to about the seventh or eighth course. Its position and the shape of the cuts show that the force was applied nearly vertically. The general direction of the line of the gashes is from west to east, in the direction in which the upper part of the tower lies; and I believe that all these facts go to prove the correctness of the theory given above, i. e., that the upper part of the tower, leaning perhaps to the east (and here the influence of the wind may have come in), dropped when the supporting lower sheets were ripped off, struck the base and cut the western gashes; that then the reaction of the water which was escaping from the up-tilted western edge, together with the rebound of the mass, accomplished its projection towards the east, cutting more gashes as it went. I believe that the upper part of the tower was rotating when it struck the base, and its rotation was probably due to the fact that the western sheets ripped off more rapidly than those to the east, as shown by the greater distance to which they were thrown, and the great length of sheet No. 28. The reaction of the water against the sheets on the east side, which held for an instant, helped turn the tower, and also probably helped to start it moving to the eastward. That this rotation was in the direction of clock-hands is shown by the gashes; by the way the balcony fence ripped off from the top, and by the position of the two bottom courses of the upper part of the tower.

No "leak" had been reported previous to the wreck. A rusty streak, about 30 to 35 ft. up, and to reach which the long ladder was required, was painted over and the ladder taken down before the tower burst. Yours truly, Dabney H. Maury, Jr.,

Superintendent Peoria Water Co.

Peoria, Ill., April 11, 1894.

APPENDIX III.

SPECIFICATIONS FOR MATERIAL AND WORKMANSHIP IN CURRENT PRACTICE.

Introductory.—In reviewing the many important matters suggested in the foregoing pages of this book the designer and builder of stand-pipes finds none which demands his thoughtful consideration more urgently than the enforcement of proper qualities of material and workmanship. The relation between this matter and the question of reform in this now important field of construction is, indeed, so intimate, and its bearing upon the duty of those responsible for the safety of this class of structures is so apparent, that the presentation of an outline of the tendencies of stand-pipe specifications at the present time seems to be warranted.

Owing to the comparative scarcity of matter relating directly to this subject, either in works of reference or in the files of technical periodicals and society proceedings, it has been necessary to a large extent to obtain facts and data through independent private sources. Among the authorities consulted for this purpose are a number of the more prominent stand-pipe designers and builders and plate metal manufacturers, dealers and consumers of the United States. Matter of much value was also obtained from recognized authorities in the field of structural tests. Much informaion of a valuable character and many sets of specifications of a recent date have been obtained with the understanding that the sources from which such matter was drawn should not be publicly identified therewith. Although personal acknowledgments cannot here be made, it would be unjust to omit the observation that those whose practice is distinguished

by the most progressive ideas and methods are also most liberal and enthusiastic in supporting measures which tend to elevate the standard of quality in this field of construction.

An eminent authority has stated the legitimate functions of the specification to be: "First, an effort on the part of the consumer to tell the producer what he wants; and secondly, it is of the nature of a contract equally binding both the consumer and producer to its provisions." Directing attention to the first of these functions, it may be stated as a recognized principle among good authorities that specifications for structural work should be not only so strict as to exclude all material and workmanship which does not meet the required standard of quality, but also so broad as to permit the use of all that certainly will not lower the adopted standard, the said standard being fixed in accordance with the true requirements of the case. Violations of this common-sense principle may usually be traced to ignorance of the conditions which may be imposed upon the structure, or of the qualities of workmanship and material which may be available or desirable for the specified purpose. Such misconceptions tend usually to a reduced standard of excellence through leniency, but the fact should not be overlooked that much harm may result also from the adoption of needlessly severe and perhaps impracticable requirements. By no means the least evil which may grow from the last-named tendency is the prejudice which it may entail upon the inauguration and prosecution of a reform. However, low-grade work is not the result of ignorance alone, for it is an unfortunate fact that dishonest motives not infrequently control either the preparation or the interpretation of specifications, and usually, if the former, also the latter.

There is much to support the assertion that stand-pipe specifications are frequently of too meager a character. Possibly this fault is a relic

of the former custom with many users of wrought iron plate of specifying merely the trade designation of the metal desired, and providing that the tensile strength, brand, and maker's name be stamped on each plate. Whatever may be the cause or excuse for such deficiencies, either in quantity or kind of requirements, it is now conceded by most authorities in structural work that specifications should make distinct provision for adequate inspections and tests. Contemporaneously with the development of such a series of tests in other lines of structural work, the more progressive engineers engaged in stand-pipe design and construction have evolved a similar system adapted to the needs of that line of work. However, it appears that this development has in no important feature followed lines dictated by the behavior of stand-pipes themselves, but that it has merely kept pace with the evolution of methods and ideas in the closely related field of steam boiler construction. The details of the structural tests themselves have, of course, shared the modifications which have, from time to time, been made by the introduction and general adoption of the testing machine.

There are still a few engineers who favor the former quite prevalent plan of accepting the reputation of the maker, in lieu of the regular tests of quality. It is but simple justice to the high integrity of the product of a number of plate metal manufacturers to concede that the plates sent to the market by them, when of guaranteed brands, might be used in large quantities without the enforcement of the usual tests of quality with little probability of serious result; but, however desirable it may seem to makers of high reputation, that such a plan should be adopted, the present very natural demand for open competition has advantages which, in the minds of a large majority of those concerned, are sufficient to outweigh those of the plan referred to. The ideal plan from the

standpoint of safety alone would, of course, be to choose the metal from the stock of a proven maker and then enforce the tests with full strictness for corroborative purposes. Such a system in effect is, and through an extended period has been, practised by a pioneer stand-pipe designer, who specifies that the steel shall be of "acceptable quality and manufacture." The above criticism of meagerness does not with justice apply to the practice of the engineer here referred to, although his specifications designate merely the elastic limit and the ultimate tensile strength required, in addition to the brief but comprehensive statement above quoted. Under the authority of the "acceptable quality," a set of detailed instructions covering a series of rigid tests, both physical and chemical, is issued to his inspector, who is required to return to him all test samples, with full certificates of the inspections and tests, which are preserved with much care. While the results attained in the case mentioned have been of the highest quality throughout, that fact does not altogether commend the omission from the specifications themselves of the detailed description of the required tests. With such omission supplied, the only criticisms, if any, to be made would come from either the consumer, who must pay for the privilege of selecting the maker of the plates, or the plate manufacturers whose product is shut out of competition. The engineer who adopts a system giving to him the power to select the producer, of course, imposes upon himself added responsibility, both as to quality of the metal and because of the usual imputation of dishonest motives in such practice.

Choice of Metal.—In weighing the relative merits of steel and wrought iron as materials for the construction of stand-pipes, it may not be denied that each metal has points of excellence possessed either in a less degree, or perhaps not at all, by the other. Judging alone from the recorded fail-

ures of the two metals in actual service, wrought iron appears to be preferable to steel. However, an entirely just interpretation of this record must recognize the fact that a majority of the total failures of steel stand-pipes may be traced to the use of ill-adapted or exceptionally inferior grades of that metal. With this qualification, the contrast in the records of the two metals is much reduced, if indeed it is not quite eliminated. Careful consideration of the foregoing records and facts related thereto leads to the following conclusions:

(1) That steel plate of cheap grades is certainly a dangerous material to use in the construction of stand-pipes.

(2) That steel plate of proper quality is a safe material for the construction of stand-pipes.

(3) That wrought iron plate, equivalent in quality to the usual grades of that metal hitherto employed for stand-pipe construction is a safe material for this purpose.

The first of these conclusions is substantiated by a number of the more widely-known failures of steel stand-pipes. The second is warranted by the scarcity of failures of steel stand-pipes, in whose construction proper grades of plate metal were used. The truth of the third is evidenced by the several classifications of accidents and failures.

The decided preference for steel, which has grown so rapidly in other fields of work, applies with full force in the construction of stand-pipes, and it has now reached such a stage that exceedingly few concerns make a specialty of building wrought iron stand-pipes. An important result of this evolution, which in the future may require a qualification of the third conclusion above stated, is thus described by a recognized authority in the field of structural tests:

> Steel for most structural purposes has so far replaced wrought iron that it is now difficult to get competition among the manufacturers of wrought iron for structural purposes. Many of the manufacturers who

are still making wrought iron find that the demand is so much greater for steel—and in fact, the profit better in steel—that they are not putting the care and attention to the manufacture of wrought iron that they have in the past, and it is getting every month harder and harder to obtain the best grades of wrought iron for structural purposes. There are, however, still a few concerns who are holding up their reputation and manufacturing as good wrought iron as in the past.

Another authority in the same field expresses the opinion that:

The quality of wrought iron is about the same as it was before the "era of steel," but engineers and inspectors who have to deal with materials for structural purposes are no longer as familiar with iron as they were some time ago, or as they are with steel.

In view of the conflict of opinion indicated by the expressions above quoted, particular interest attaches to the following statement from a well-known firm of boiler-plate merchants, having an experience covering a period of more than a half century:

There are very few mills to-day that have among their employees men who can make first-class iron, and by reason of the fact that orders for iron are so exceedingly rare and these men can be put at the work only at infrequent intervals, their skill has departed and they have no longer the ability to make as good iron as was made five or ten years ago.

Whatever be the present status of the question, it is pertinent to observe that the results of a very similar rivalry between steel and wrought iron in the manufacture of T-rails, some years ago, tends forcibly to confirm the belief that the quality of the superseded metal must decline sooner or later in the case under consideration. Such deterioration having taken place, it seems quite certain that wrought iron could show no superiority over steel in open competition, and, as remarked in discussing this subject at the conclusion of the original record of accidents, it seems altogether probable that the favorable showing of wrought iron indicated by the record of stand-pipe failures would soon be forfeited were the extensive use of wrought iron for

this purpose to be suddenly resumed without a corresponding restoration of the former qualities of that metal. Fortunately, the few firms which have adhered loyally to the use of wrought iron and have built most of the large wrought iron standpipes during the period of alleged retrogression, seem to have recognized the importance of using good grades of that metal, so that the decline in safety, above suggested, has probably not begun.

Very naturally the reduced cost of steel, attended by a growing confidence in its uniformity and high quality when demanded, has led to a decided preference for that metal. That this preference will not be modified under present conditions seems very certain, but this fact will not, and very properly should not, prevent the use of wrought iron of appropriate grades when preferred. Since little assurance of excellence is to be found in the mere names steel or wrought iron, the really vital consideration is not so much which metal as what grade of the chosen metal.

Steel Plate.—The usual market grades of steel plate may be described as follows: Tank steel is the cheapest grade. Its low price is due primarily to the grade of stock used, giving a metal with high percentages of the detrimental elements, even without the careless manipulation which cheap work is so apt to receive. The quality of the tank steel produced by a few makers is sometimes quite good, but experience has shown it to lack uniformity, and good authorities generally agree in condemning its use in important structures. While it may display the physical excellence of the best grades of steel, "it is apt to be hard and brittle and should never be used in any part of a standpipe." It is believed by some that a fruitful cause for the treachery of tank steel is to be found in the practice of selling under that classification steel plate which has been rejected from higher grades. It is common to find merely the tensile strength of

this grade of steel specified, "60,000 T. S." being the usual requirement.

Shell steel is the next better grade. Its greater excellence and enhanced cost are due to the use of more care in selecting the stock and in perfecting the chemical nature of the finished product. Shell steel is used in ordinary boiler construction and many stand-pipes have been built from it. It is, of course, preferable to tank steel, but the best practice demands a better grade for high quality boiler and stand-pipe construction. A good authority states the following as a fair specification for shell steel:

Soft (preferably open-hearth) steel having a tensile strength between 55,000 and 64,000 lbs. per sq. in., an elongation in 8 ins. of not less than 20%, and a reduction of area at the broken section of not less than 40%. Specimens of any plate having a width not less than four times the thickness, when heated to a cherry red, and quenched in water, shall bend cold through 180° about a diameter equal to its thickness, without showing any signs of failure whatever.

Flange steel, the grade next above shell, is distinguished by its uniformity, high ductility and usually low tensile strength. It is the grade of steel plate adopted in the best practice for the construction of steam boilers and stand-pipes. Specifications for flange steel will be outlined in the discussion below.

Ordinary firebox and locomotive firebox are still higher grades of steel boiler plate, possessing special properties which fit them for the uses indicated by their trade designations.

The above general classes of steel plate are, of course, subject to variations which are common to such trade distinctions, so that the excellence of a low grade of steel of one maker is often greater than that of a higher grade by another maker's classification. The prices of the several grades of steel plate, on Jan. 1, 1895, are given in the accompanying table.

Prices in Cents Per Pound of the Usual Market Grades of Steel Plate, Jan. 1, 1895.

Grade of Steel.	New York.	Pittsburg.	Chicago.
Tank	1.25 to 1.40	1.15 to 1.25	1.35 to 1.40
Shell	1.40 " 1.45	1.30 " 1.35	
Flange	1.50 " 1.65	1.35 " 1.40	1.50 " 2.00
Ordinary firebox	1.75 " 2.00	2.50 " 3.75	2.00 " 4.50
Locomotive firebox	2.00 " 2.25	3.35 " 3.50	

Some stand-pipe specifications designate merely a minimum tensile strength for the plate. This practice is criticised because of the danger of cracking with high tenacities in steel plate, and it is the practice of a few engineers to provide especially severe ductility requirements for steel plate showing high tensile strength. By far the most common method of specifying tensile strength for stand-pipe steel is to fix a double limit, as in other classes of structural specifications. It is usual practice to fix these limits from 5,000 to 10,000 lbs. per sq. in. apart, the nominal strength of the metal being about midway between them. The elastic limit, when specified, is usually required to be at least one-half the ultimate strength, or a minimum value about equal to or somewhat greater than one-half the nominal strength of the metal is adopted.

There is lack of uniformity among stand-pipe designers in the matter of ductility requirements. Those engineers who lean toward boiler practice usually omit a specification for reduction of area at fracture, while those who adopt the methods used in bridge and similar metal structural work generally include requirements for both reduction of area and elongation. A controversy waged between the two has, in reality, had little foundation, since all agree that elongation is to be given the greater weight in judging of the quality of the metal, and those who advocate a requirement of a specified percentage of reduction of area do so only for the purpose of throwing additional light upon the subject, particularly when considered in connection with the character of the fracture. A well-known testing engineer remarks that he has often found

samples of steel which have given ample elongation, but "in which the reduction of area was way below that which would ordinarily be required, and where the fracture showed crystalline and burned steel." The same authority admits the uncertainty which often attends the determination of the percentage of reduction of area in the case of wrought iron, because of obliquity of fracture. The advocates of the double designation have very wisely sought to select practical values for the two percentages from the results of extensive series of tests of the several grades of steel, and there is promise of quite general adoption of the values so determined. In these values the minimum percentage of elongation in 8 ins. is equal to about one-half that of reduction of area, the test piece to be as near ½ sq. in. in sectional area as possible. The following distinctive physical properties have recently been recommended by the most extensive producers of structural steel in the United States, and have received sanction in the practice of a large number of prominent engineers, including well-known testing engineers:

	Kind of Steel.		
	Soft.	Medium.	Hard.
Tensile strength, minimum, lbs. per sq. in.	54,000	60,000	66,000
Tensile strength, maximum, lbs. per sq. in.	62,000	68,000	74,000
Elastic limit (compared with ultimate tensile strength)...	½	½	½
Minimum elongation, in 8 ins., per cent.	26	20	18
Minimum reduction of area, per cent.	50	40	35
Cold bend test without sign of crack or flaw on outside of bent portion, diameter of curve in terms of thickness of test piece (to bend 180°).	(flat)	1	3

The above qualities for soft steel have been adopted in several recent stand-pipe specifications with the addition of a suitable cold-bend quenching or temper test.

The practice of varying the percentage of elongation with the thickness, recommended by the Am-

erican Boiler Manufacturers' Association, in 1889, has been followed by several stand-pipe designers. The essential features of the "A. B. M. A. Standard Specifications" are as follows:

To be homogeneous steel made by the open-hearth process, and having a tensile strength of 55,000 to 62,000 lbs. per sq. in.; an elastic limit not less than 32,000 lbs. per sq. in.; an elongation in 8 ins. of 20% in plates ⅜ in. thick and under; of 22% for plates ⅜ to ¾ in., and of 25% for plates ¾ in. thick and over; cold bend test without signs of distress, for plates up to ½ in. thick flat on itself, and for plates thicker than ½ in. around a mandrel having a diameter 1½ times thickness of plate, 180°; to contain not more than 0.04% phosphorus, nor more than 0.03% sulphur.

Another method of varying the ductility requirement with the thickness of the plate is shown in the stand-pipe specifications of a prominent engineer who requires:

For plates ⅜ in. thick and heavier, elongation to be not less than 25% longitudinally on plate, and 22% transversely on plate. Plates thinner than ⅜ in., elongation to be not less than 22½% longitudinally and 20% transversely.

The same engineer specifies a phosphorous limit of 0.06%.

The cold bending test furnishes tangible proof of the ductility of the metal under conditions approaching those of actual practice, and the quenching test, when properly executed, gives evidence of the possible influence of local heating and working. These two tests are also credited with much value in detecting burnt and high-phosphorus steel, although an eminent authority, quoted below, states that steel containing an excess of phosphorus sometimes displays high ductility. The bending tests adopted for the steel used in a stand-pipe, built in 1894 by a prominent Western engineer, were as follows:

Specimens to bend cold, or after being heated to a cherry red and quenched in water at 70° F., on an anvil or in a testing machine, doubling the specimen and pressing it flat, without sign of fracture on the outside of the bent portion.

Another stand-pipe designer adopts the following provisions in relation to character of fracture and bending tests, from Cooper's "General Specifications for Bridges":

> All broken samples must show uniform, fine-grained fractures of a blue steel-gray color, entirely free from fiery luster or a blackish cast. . . . Before and after heating to a light yellow heat and quenching in cold water this steel must stand bending 180° to a curve whose inner radius is equal to the thickness of the sample, without sign of fracture.

Other engineers designate quenching temperatures different from that above quoted, 80° and 82° F. being common values. The "Committee on Standard Tests," of the American Society of Mechanical Engineers, recommends a quenching test for boiler steel, "heated throughout to a dull cherry red (1022–1202° F.) and quenched in water of a temperature of 25° C. (77° F.)," after which the piece is bent about a stud practically 1-in. in diameter, regardless of the thickness of the sample, as in the German practice. Other specifications for stand-pipe steel fix the diameter of the 180° bend for quenching test at 1½ times the thickness of the sample, and this may be regarded as the most lenient requirement for thick plates that will give a fair assurance in relation to the quality thus tested.

The recent failure of a large steel stand-pipe has drawn attention to the fact that the specifications for the plate metal were grossly deficient in the matter of ductility requirements. Not only was there no reference whatever to either elongation or reduction of area, but the specification for a cold bending test was of an astonishingly deficient character. The provision referred to was as follows:

> The metal of the plates must be . . . sufficiently ductile to admit of rolling while cold around a radius of 20 ins., without developing flaws, cracks, splits, or any other features which would render them unfit for the work in the opinion of the engineer.

That the defect was not accidental is shown conclusively by specifications prepared by the same en-

gineer subsequent to the failure referred to, in which the radius of the required cold bend curve was reduced from 20 to 12 ins.

The practice of designating the process by which steel plate shall be made is in much favor with many prominent engineers and boiler-plate dealers of high reputation. One authority states that "the best grade of acid or basic open-hearth flange steel should be used for stand-pipe construction, since less high in phosphorus and sulphur, is wholly unsuited for that purpose." It should be remarked, however, that the designation of the process alone may give little assurance of excellence, a matter common Bessemer steel, which is generally more or which was recently discussed editorially in the columns of a trade journal as follows:

The terms "Bessemer" and "open-hearth" steels have reference to methods or processes, and not necessarily to qualities. If a good quality of pig iron is made into steel by either the Bessemer or open-hearth process, it would be found that the latter was softer and more uniform under the stress of severe usage. But Bessemer steel made of good iron is better than open-hearth steel made of a cheap and inferior material. Therefore the Bessemer tank steel of some manufacturers will run better than the open-hearth flange steel of other makers. The name don't make the quality.

Granting the wisdom of specifying the process of manufacture, strict consistency compels the adoption of chemical limitations. Phosphorus is properly regarded to be the most dangerous element in structural metal, and it is now comparatively common practice to designate a phosphorus limit even where no reference is made to the process of manufacture. According to Howe:*

Phosphoric steels are liable to break under very slight tensile stress if suddenly or vibratorily applied, or shock-like. . . . Phosphorus diminishes the ductility of steel under a gradually applied load, as measured by its elongation, contraction and elastic ratio when ruptured in the ordinary testing machine; but it diminshes its toughness under shock to a still greater degree, and this it is that unfits phosphoric steels for most purposes. The influence of 0.01% of phosphorus is perceptible—that of

*"Metallurgy of Steel," pp. 68-9.

0.20% is generally fatal in ingot metal. . . . The effect of phosphorus on static ductility appears to be very capricious, for we find many cases of highly phosphoric steel which show excellent elongation, contraction, and even fair elastic ratio, while side by side with them are others produced under apparently identical conditions, but statically brittle. . . . And it appears reasonably certain, though exact data sufficing to demonstrate it are not at hand, that phosphoric steels are liable to be very brittle under shock, even though they may be tolerably ductile statically.

The fact last quoted from so authoritative a source affords a most potent argument in favor of the adoption and rigid enforcement of a proper phosphorus limit for stand-pipe steel; for, while the physical properties indicated by the faithful execution of the usual structural tests will, in a majority of cases, reveal the presence of an excess of phosphorus, the possibility of selecting samples of a particularly ductile character, as above suggested, is very obvious. A testing engineer of ripe experience discusses the amount of the phosphorus limit as follows:

It has been found that while some good steel has been made that has stood splendid physical tests in every way with over 0.08% phosphorus, at the same time, where the quantity of phosphorus runs over 0.08%, the amount of defective steel is very rapidly increased. For such purposes as stand-pipe plates I certainly recommend that the requirement for phosphorus be even lower than 0.08%, namely, a maximum of 0.05%. . . . For ordinary stand-pipe steel, I would say to have a requirement of not over 0.08% of phosphorus; for best grades, a requirement of not over 0.05% phosphorus.

Some light is thrown upon the question of availability of good grades of steel for stand-pipe construction by the following statement, obtained from a steel-plate manufacturer of high reputation:

We have made everything from ordinary tank steel up to a fine quality of boiler steel for stand-pipe construction. While an ordinary steel may meet almost any physical specification very nicely, it is inclined to be brittle, and we do not deem it good enough for stand-pipes. Of late we have furnished quite a number of stand-pipes which call for steel to show below 0.06% phosphorus, and this we think a very good grade. . . . To our minds, a steel showing 55,000 to 62,000 lbs. per sq. in. tensile strength, 26% elongation in 8 ins., 50% reduction of area, and 0,05 to 0.06%

phosphorus, would make an excellent stand-pipe, and, at the same time, would not be a very expensive grade of steel, although it would cost considerably more than common tank steel.

A recent proposal for the construction of an important stand-pipe in a Western city included bids according to five limitations for phosphorus, running from 0.08 to 0.04%, inclusive. The relative bids on the superstructure for the several grades of steel, taking that for the highest phosphorus limit as unity, were as follows:

Phosphorus limit, per cent.	Relative bid.
0.08	1.00
0.07	1.03
0.06	1.08
0.05	1.17
0.04	1.23

The plates were to be "soft, acid, open-hearth steel," of 54,000 to 62,000 lbs. per sq. in. tensile strength; elastic limit, 31,000 lbs. per sq. in.; minimum elongation in 8 ins., 26%; minimum reduction of area, 50%; cold bent flat; and not more than 0.08% phosphorus, and less per cent. as per detailed bid.

There is lack of uniformity in the number of tests required for the plate metal. Many engineers do not state the number in the specifications, but include that detail in the special instructions to the inspector, or leave the matter to the judgment of the inspector. It is the custom of a well-known testing concern to require at least one complete test of each open-hearth melt or Bessemer blow of steel, and to require each melt or blow to be kept separate and the number stamped on each plate; also to require, in addition, one test for each widely-varying thickness, in which this melt of steel may be rolled, and a test for each widely-varying difference in the treatment of the steel in the rolling or other operation in its manufacture. It is deemed wise to adopt some such basis as the above, as it "will give the inspector a right to require a test if

he thinks that an ingot has been overheated, or anything of a similar nature." One stand-pipe designer, who has maintained a high standard of quality through many years, requires that "the test specimens shall, in all cases, be taken from the shearings of at least 20% of the plates produced from each melt, the plates or sheets to be selected at random by the inspectors." Others base the number of tests on the different thicknesses of plate required in the work.

In fixing the character and extent of the tests which are to be imposed upon plate metal, it is of the first importance to determine the method by which they are to be enforced. It is the practice of a few engineers to specify that the tests shall be made by the contractor or by the manufacturer, but the best authorities favor independent tests by competent and impartial specialists in that line. To this end it is conceded by foremost authorities in this and other classes of structural work that the maximum attainment of high quality, and hence of safety, is found in the employment of one of the several testing bureaus or laboratories of recognized integrity, which are now accessible to any part of the country. In addition to the tests made by such concerns, usually executed at the mills, it is the custom of several stand-pipe designers to require the contractor to furnish a series of certified samples, in order that corroborative tests may be made by the engineer personally. Others require that the testing engineer, in giving certificates of the behavior of the metal during test and of its chemical nature, shall return the tested samples, with proper identification to aid in their interpretation. It should be stated that the foremost practice in stand-pipe construction regards with the highest favor the prescription and faithful enforcement of such measures looking to the elevation of the standard of safety in the completed structure.

Wrought Iron Plate.—The several market grades

of wrought iron boiler plate are described as follows:*

Tank iron is the cheapest grade and is used only for the most unimportant purposes. Refined iron is used when strength and toughness are not specially demanded, and where no risks are involved. Neither of these grades should be used in boilers or in any structure of great magnitude or value. Charcoal No. 1 iron (C. No. 1) has a tenacity exceeding 40,000 lbs. per sq. in., is hard, but not very ductile, and is never used when flanging or considerable change of form is required, as it is apt to break at the bend. Charcoal hammered No. 1 shell iron (C. H. No. 1, S.) is a better worked iron than C. No. 1; but it is not always hammered. It is stronger, having a tenacity of 50,000 to 55,000 lbs. per sq. in. in the direction of the fiber, and 75 to 80% of this amount across the grain. Although distinctly made for the shell of the boiler, the best makers generally prefer to use better grades for that purpose. A better quality known as flange-iron (C. H. No. 1, F.) is much more ductile and may be worked into flanged sheets: it is nearly equally strong is both directions and has about the tenacity of the preceding. Other higher grades such as flange fire box (C. H. No. 1, F. F. B.) are made for special purposes.

The following standard specifications for flange-grade iron used by the Baldwin Locomotive Works (Jan. 1, 1893) illustrate the qualities of wrought iron which may be secured at the present time upon proper inspections:

All boiler iron plates are to be of C. H. No. 1 flange quality, and to be made from best charcoal iron blooms. A careful examination will be made of every plate, and none will be accepted that show mechanical defects. A test piece, 1½ ins. wide and 24 ins. long, to be furnished from each plate rolled. No plates will be accepted whose test pieces show an ultimate tensile strength, with the grain, of less than 50,000 lbs. per sq. in., or less than 45,000 lbs. per sq. in., across the grain, or whose elongation falls below 20% in a section originally 2 ins. long. A drifting test will be made of at least two test pieces from each shipment, and no plates will be accepted which will not permit of a 1¼-in. hole being drifted out to 3 ins. diameter. Any plate which develops defects in working will be rejected. Each plate must be stamped with the maker's name, brand of the iron, and the guaranteed tensile strength.

Owing to the limited extent to which wrought iron has been used in the construction of standpipes for some years past, the collection of specifi-

*Compiled from Thurston's "Steam Boilers," pp. 96-7.

cations for wrought iron stand-pipes of recent date has been attended with much difficulty. For this reason the discussion of specifications for wrought iron plate cannot be made as extended as that for steel plate. The specifications for plate metal used by a prominent engineer in the construction of a number of important wrought iron stand-pipes previous to his adoption of steel for this purpose, some years ago, were as follows:

The iron to have a minimum tensile strength of 50,000 lbs. per sq. in. sectional area, all to be of best charcoal hammered No. 1 iron, and each plate to be stamped C. H. No. 1, together with the name of the manufacturer. All plates to be inspected at the rolling mill, and tested under the supervision of the inspector appointed by the engineer.

A stand-pipe of some importance was built in 1893 from wrought iron, which was required to "be tough, fibrous and of uniform quality, and resist a tensile strain of 48,000 lbs. per sq. in."

In the construction of an important pipe line on the Pacific Coast, recently, the contractor was permitted to use either wrought iron or steel, the pipe being built from riveted plates. The steel plate specified was of the same quality as that used by the designing engineer in the construction of stand-pipes, and it may be inferred that the specifications for wrought iron plates for alternative use in the pipe line represent his standard of quality in the latter metal for stand-pipe construction. The requirements for wrought iron were as follows:

The wrought iron plates must be ductile, fibrous, of uniform thickness and free from blisters, seams, buckles, cinder spots, or rough or imperfect edges, and must admit of cold hammering or scarfing to a fine edge without cracking. It must be capable of being bent cold without fracture on a curve of diameter not over twice the thickness of the plate, 180° in the direction of the fiber, and 90° at right angles to the fiber.

Under test, the elongation in a length of 8 ins. must not be less than 15%; the reduction of area at the section of fracture, not less than 40%; the limit of elasticity, not less than 25,000 lbs. per sq. in.; and the ultimate tensile strength, not less than 50,000 lbs. per sq. in., which must be stamped on each sheet

as a guarantee by the maker of the quality of the iron.

The thickness of these iron plates was about ¼ in. and the width was 60 ins. The steel specifications on the same work required "soft, open-hearth steel," to contain not more than 0.06% phosphorus or of sulphur, and not more than 0.60% manganese; the elastic limit to be 30,000 lbs. per sq. in.; ultimate tensile strength, 55,000 to 65,000 lbs. per sq. in.; elongation in 8 ins., on plates ⅜ in. thick and less, 22½% longitudinally, and 20% transversely; cold bend, flat.

The degree of ductility required for wrought iron boiler plate in the "Rules of the United States Inspectors of Steam Vessels" (January, 1894), is as follows, the antiquated grooved "marine" section being retained, notwithstanding vigorous protests against it:

Iron of 45,000 lbs. per sq. in. tensile strength shall show a contraction of area of 15%, and each additional 1,000 lbs. tensile strength shall show 1% additional contraction of area up to and including 55,000 T. S.

The former quite prevalent plan of depending upon the time-earned reputation of the maker of wrought iron plate as a guarantee of quality may, perhaps, be more than ever advisable if the alleged deterioration has taken place. However, the engineer is rarely permitted to select the producer of structural metal, and since stand-pipe construction is no exception to this rule, it is the duty of the designer to impose upon the iron such tests as will insure the desired standard of safety in open competition.

Rivet Metal.—While it is the very general practice to use soft steel for power-driven rivets, most authorities concede that field rivets should be wrought iron. Since the two metals are known to be damaged about equally by working at a blue heat,*

*"Mild Steel for Structural Purposes," Engineering News, Vol. XXVII., p. 43 (Jan. 9, 1892). Also, "The Working of Steel," Proceedings Institution of Civil Engineers, Vol. LXXXIV., pp. 114-214 (1886), reprinted in "Naval Professional Papers," No. 21.

this preference for wrought iron, if consistent, must depend upon some other assumption than that wrought iron rivets may be finished at a lower temperature than steel rivets. As a matter of fact, wrought iron rivets may be heated to a considerably higher temperature without damage to the metal than is permissible with steel rivets, and this affords a defense for the preference which has, perhaps, resulted from practical test rather than from a consideration of critical temperatures. Upon this point of maximum permissible temperature a firm making a specialty of structural inspections states that:

> Steel rivets should not be heated to over an orange color, much less than the heat put upon iron rivets, which are heated to nearly a lemon color, often without apparent injury.

A well-known authority in this class of work comments as follows on the same point:

> Iron rivets are ordinarily heated up considerably hotter than steel rivets in using them. An iron rivet can be heated to what is called a "wash heat"—a temperature at which the intermingled slag in the metal begins to soak out from it—and this temperature can be safely attained without over-heating the wrought iron rivet. A similar temperature put upon a steel rivet would occasion the steel to be subject to such oxidation as would make it red-short.

A recent treatise* discusses the subject of field riveting as follows:

> Field rivets are generally of wrought iron in all cases, as the difficulty of driving good steel rivets prohibits their use. The range of temperature at which steel can be effectively worked is very small, and, as in field riveting, considerable time is lost in passing the rivet from the forge to the riveters, a rivet has time to cool to a point below which it is not advisable to do any work upon it, as would be necessary in driving it.

One well-known engineer who uses steel rivets in stand-pipe construction specifies that "the heating forge shall be kept on the staging contiguous to the work." This designation of a precaution which is almost always observed on such work as a mat-

*Johnson's "Modern Framed Structures," p. 257.

ter of convenience indicates that the engineer referred to had in mind the necessity of rapid work with steel rivets. It should be remarked, however, that he makes no other requirement for the rivet metal than that the "rivets shall be of steel, capable of an ultimate resistance to shearing of 45,000 lbs. per sq. in." The specifications for an important steel stand-pipe, built in 1894 upon the design of a prominent engineer, made the following provision for the rivet metal:

> Steel for rivets shall have in test pieces ¾-in. in diameter. an ultimate tensile strength of from 48,000 to 56,000 lbs. per sq. in., and an elongation in 8 ins. of 26%. Heated uniformly to a light yellow, and cooled in water at 82° F., it shall bend around a circle of diameter equal to 1½ times the thickness of the specimen without fracture. Full-size rivet bars shall bend cold and double flat on themselves without sign of fracture on the convex side.

Accepting the standing of the engineers, above quoted, and the high quality of the work hitherto executed by them, as proof of the fact that steel rivets may be used with success for stand-pipe construction, there is sufficient cause to believe that the general adoption of steel rivets for this purpose would not be wise, at least under the present almost, if not quite, universal practice of riveting by hand. Granting that the selection of wrought-iron is well sustained by the practical features involved, the necessity of discriminating between good and bad grades of that metal presents itself. It is asserted that "the manufacture of wrought iron rivets has become a specialty, so that the only reasonable assurance of securing the best grade is found by wording the specifications so that the contractor will use the desired make." Such is apparently the opinion held by a very considerable number of engineers engaged in this class of work, among the number being some of the most progressive known to the profession. On the other hand, it is urged that open competition should be allowed in the matter of rivets as in other classes of structural ma-

terial as a matter of strict fairness to all concerned. A defense of the practice of making an exception of the rivets in this regard is found in the fact that for small jobs, such as the construction of most stand-pipes, the rivets are purchased by the keg in relatively small quantities, so that to incur the expense of a special rivet-rod test previous to the manufacture of the rivets would usually be looked upon as an extravagant proceeding. Indeed, the obstacles in the way of carrying into execution such a preliminary test are so great as to suggest that it would prove a dead-letter provision in a large majority of cases. A proper regard for the question of practicability demands a test of the rivet metal which may be performed during erection both readily and effectively. The following valuable opinion bearing upon such a practical test has been obtained from an authoritative source:

With rivets, as purchased by the keg, for field riveting, in any large work, I would advise their being made from iron which had been specially tested and subjected to inspection; but where this is made impracticable, as in small jobs like stand-pipes, then more care should be taken with a test, which I believe to be the best in any event, as to the quality of the rivets—that is, that rivets put up as in actual practice, either machine or hand driven, shall be of such quality, and the work upon them shall be of such a nature that when any of these rivets are cut out from the work, with a cold-chisel or blows from a sledge, they shall cut out strong and shall not "fly," showing brittle material, under this treatment. This is a simple, practical test, which can be made anywhere.

The wording for a clause describing such a practical field test may be obtained by revision of the following excellent rivet-rod test, taken from a set of "general specifications":

Rivet iron shall . . . be capable, without cracking or serious abrasion, of being heated to a good forging heat and made up either by machine or handwork into rivets, and of again being heated to a good red heat, forged as in riveting, allowed to cool, and upon being nicked and cut out of the work, it must show a good, tough, fibrous structure without any crystalline appearance. Rivet iron shall especially be required to flow well in riveting, and to be neutral in character and tough in fiber after being riveted.

A practical and easily-executed hammer test has

recently been used by the U. S. Navy Department for steel rivets employed in boiler construction. Each ton of rivets from the same heat of steel was termed a "lot" for the purpose of testing. The hammer test was as follows:

> From each lot twelve rivets are to be taken at random and submitted to the following tests: Four rivets to be flattened out cold under the hammer to a thickness of one-half the diameter, without showing cracks or flaws. Four rivets to be flattened out hot under the hammer to a thickness of one-third the diameter without showing cracks or flaws—the heat to be the working heat when driven. Four rivets to be bent cold into the form of a hook with parallel sides, without showing cracks or flaws.

Although specifications sometimes fix the shearing strength that the rivet metal shall have, it is not often that such tests are actually made. In this connection the following statement by a prominent testing engineer is of much value:

> With rivet iron, the proportion of the shearing strength to the tensile strength is about 72%; and with rivet steel (having a tensile strength from 52,000 to 60,000 lbs. per sq. in.), the shearing strength is from 75 to 80%—ordinarily fully up to 80%—of the tensile strength.

Reviewing the entire matter of rivet metal, it may be concluded that under present conditions and methods of work the safest and most satisfactory results in stand-pipe construction are to be had by using the best available grade of soft charcoal iron rivets. Whether this end is to be accomplished by special reference to a certain make of iron rivets, as a standard of quality, or by severe physical tests, must depend upon the judgment of the individual engineer, but in any event he should get the best.

Workmanship.—As in other classes of structural specifications, it is wise to provide that "all workmanship shall be first-class in every particular," or the equivalent of that expression, in order to prevent the use of inferior methods in points of doubtful interpretation. It is also the practice of some engineers in stand-pipe construction to state specifi-

cally the right to reject any material in which flaws may be detected at any stage of the work at the expense of the contractor. The enforcement of such requirements, of course, demands that provision be made for adequate inspections, not only of the plates originally at the mills, but, in addition, both of the methods of workmanship and the behavior of the metal during the several stages of the shop work and erection. It has been by no means universal practice to provide such inspections of workmanship, even where there has been a proper regard for the quality of the material. Where such enforcement is to be neglected, it would seem that considerations of strict consistency and professional honor demand the omission from the specifications of these provisions, since they may afford but a false sense of security.

The fact that the damage sustained by the metal adjoining rivet holes in the process of punching increases with both the hardness of the metal and the thickness of the plate, has found recognition in the practice of various stand-pipe designers. It is the recommendation and practice of a number of authorities to require that in plates thicker than ¾ in. the rivet holes shall either be drilled, or, if punched, that the holes shall be reamed. It is stated* that, on the Pennsylvania Railroad, locomotive boiler plates are punched up to a thickness of ⅞ in. However, the standards both of material and workmanship in that case are of an exceptionally high character, so that it may not be taken as a precedent with entire consistency, unless equivalent safeguards are adopted in the execution of the work. Mr. F. H. Lewis, C. E.,** an advanced authority in the use of soft steel, after investigating the effect of thickness

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*Howe's "Metallurgy of Steel," p. 233.

** "Soft Steel in Bridges." Proceedings Engineers' Club of Philadelphia, Vol. IX., pp. 80-1 (Jan., 1892).—Eng. News, March 26, April 2, 1892.

upon the extent of damage sustained in the process of punching, as indicated by the character of the fracture, recommends that ½ in. be the maximum thickness at which punching should be permitted without reaming, and in the same connection remarks that "in practical work the efficiency of reaming, being based on punching, must clearly share the deficiencies of punching. With good punching, the reaming no doubt accomplishes its object . . . . but it is quite certain to decrease in effectiveness . . . . with bad punching." It is asserted, and apparently with much reason, that not a little of the evidence offered in the controversy concerning the method of preparing the rivet holes is selected with no regard to the conditions governing the process of punching. In this connection an experienced maker and user of boiler plate, in stating the more serious abuses in the working of steel plate, includes "punching holes in an improper manner, that is, with improper punches and dies. This is not intended to mean that drilling is necessary in place of punching, but refers to the fact that a good plate may be badly damaged by the use of improper punches and dies." The stand-pipe specifications of most careful designers state, in detail, the required method of laying out the work in the shop and of preparing the holes, and it is common practice to designate the kind and condition of the punch. Although best boiler shop practice always punches the holes from the faying surfaces for obvious reasons, it should be remarked that this important matter was overlooked in the construction of a large stand-pipe which failed recently, the specifications for which made the following provisions:

Lay out all holes carefully and accurately, and punch with a center punch, sharp and in perfect order, from the surface to be in contact, and so that the bevel of the hole may be away from the surface in contact.

It is usual to specify that the edges of the plates

shall be planed to a suitable bevel for calking, although some specifications allow them to be bevel-sheared and a few direct that the edges shall be chipped.

Steel plate suitable for stand-pipe construction will bend cold to the curve required, without damage. An expert on steel for marine boilers observes* that "if steel will not stand bending cold to the curvature required for the shells of cylindrical boilers, it should not be used, and those who do not possess rolls capable of bending plates while cold should get them." This remark was made in concluding a discussion of the causes which led to the failure of a steel plate during the construction of a boiler. The plate in question showed excellent qualities, both physically and chemically, and the only reasonable explanation of the failure was in the fact that the plate was heated to a dull red to assist in bending it, and in the judgment of the authority quoted, "there is no doubt that it was bent when it had cooled to a 'blue' heat, at which temperature it is imprudent to bend or work steel." An experienced maker and user of boiler plate, in commenting upon the more prevalent abuses in the working of steel plate, mentions first that of manipulating it at a "blue" heat, characterizing it as "the worst form of bad working," and places next that of "local heating and working, which is almost as bad as working at a 'blue' heat, unless the plate is afterward annealed in an efficient manner." In discussing the dangers of "blue-shortness," Howe** states that

> Not only are wrought iron and steel much more brittle at a "blue" heat than in the cold or at redness, but while they are probably not seriously affected by simple exposure to blueness, even if prolonged, yet if they be worked in this range of temperature, they remain extremely brittle after cooling, and may, indeed, be more brittle than while at blueness.

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*Traill in London "Engineering," Vol. XLII., p. 482 (Nov. 5, 1886).

**"Metallurgy of Steel," p. 284.

The practice of a very few engineers of requiring that all plates shall be bent cold with suitable rolls, while doubtless unnecessary with most standpipe builders, probably has a bearing in the case of numerous smaller concerns engaged in this class of construction. It would seem, however, that the opinions above quoted in relation to the dangers of "blue-shortness" apply with special force to the scarfing down necessitated in the present nearly universal practice of using lap-riveted joints in the construction of stand-pipes. An engineer who strongly advocates the use of wrought iron for stand-pipe construction has assigned the recent failure of a large steel stand-pipe to the simple fact that the metal was steel, and, in discussing the matter, remarks* that he "cannot believe that steel is the material for stand-pipes when built with lap joints. The heating of one corner of a steel plate for the necessary scarfing and the local heating the joint must receive during erection, in order to draw it up tight, is certainly not very beneficial to any material like steel." As a matter of fact, however, this very timely criticism applies also to wrought iron, for Stromeyer** has shown very conclusively that the two metals are affected to an equally serious extent by working at a "blue" temperature. Such being the case, the remedy for the dangers referred to is seen to be attainable only in a reform in the design of the riveted joints, a matter which does not properly fall within the scope of this discussion.

It should be observed in this connection that a recent advanced design by a pioneer engineer in this field called for proposals upon three kinds or combinations of joints. The relative bids on the superstructure, taking the average of six representative bids, were as follows: (1) All joints lap-riveted, 1.00; (2) horizontal joints, lap and vertical

* Engineering News, Vol. XXXI., p. 113 (Feb. 8, 1894).
** "The Working of Steel," Proceedings Institution of Civil Engineers, Vol. LXXXIV., pp. 114-214 (1886).

joints, butt-riveted, 1.08; and (3) all joints butt-riveted, 1.21.

Referring again to the matter of "blue" heat working, it is of interest that the clause in Cooper's "General Specifications for Bridges," relating to this important subject has been adopted in the specifications of a stand-pipe built in 1894. This clause is as follows:

> No work shall be put upon any steel at or near the "blue" temperature, or between that of boiling water and of ignition of hardwood sawdust.

It is stated* that at the works of Samson Fox, at Leeds, Eng., where the highest grade of flanging steel plate is executed on an extensive scale, the test for the minimum temperature at which flanging may be performed without damage to the metal consists in placing a hardwood hammer handle in contact with the plate; "if the wood does not blaze instantly on contact, the sheet is heated until it will; if it sparks only, it is not hot enough. The shape of a sheet is never allowed to be changed until this heat is shown."

In best practice it is required that the rivet holes shall match "true and fair" in assembling the plates during erection. One engineer requires that "hot rivets must enter holes without the use of a hammer." It is sometimes allowed that the drift pin may be used "sparingly," but it is the general practice among careful engineers to prohibit its use altogether. Some designers recognize the possibility of some eccentricity in the rivet holes, even in the best of shop work, and provide that such holes be reamed out as required. It is considered excellent practice to require that larger-sized rivets shall be used for such reamed holes.

Reference has already been made to the heat at which rivets may be forged without damage and to

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*"The Boiler Maker," Vol. II., No. 3, p. 8 (March, 1894).

the temperature beyond which the rivet suffers injury from overheating.

Some require that the rivet heads be finished with a suitable "snapping hammer." In any case, it is of much importance to insure by rigid inspection that sufficient stock is provided in the rivets to fill the holes perfectly, and also to allow the formation of a full and perfect head. It is customary with a number of engineers to prohibit the calking of rivets which develop leakage, and to require that such rivets be replaced with perfect ones.

It is usual to require that the calking be done with a "round-nosed" calking tool. Some engineers require inside calking, while a few specify both inside and outside. Others provide simply that the seams "shall be calked perfectly tight," and it is sometimes added "without the use of paint or putty." It has been stated by an authority in steam boiler construction that beyond a certain limit the amount of calking required to secure permanently tight seams may usually serve as an inverse measure of the quality of the workmanship as a whole. Such a measure should appeal to the engineer in charge through the character of his inspections, and to the builder through his business reputation.

Painting.—The methods of painting stand-pipes are subject to as much variation as in other exposed structural metal work. Some require that the inaccessible surfaces shall receive two coats of red lead, while others allow the omission of paint from the faying surfaces of the seams to permit the joints to rust. It is customary to require three coats of paint, at least one of which is put on at the shop. The details of the coloring pigments, of course, vary with the preference of the engineer. Too much stress cannot be placed upon the thorough scraping and cleansing of the plates before applying the first coat of paint.

Specifications for Stand-Pipe Metal and Workmanship.

The following specifications, embodying essential and consistent features of best current practice, are presented from a conviction that all stand-pipes should be constructed from a uniformly excellent grade of material and workmanship, and that reductions of cost, when necessary, should be accomplished through increased working stresses, and not by the sacrifice of quality. It is confidently believed that a general obedience to the dictates of this principle must lead promptly to an elevated standard of safety in stand-pipe construction. It is neither advisable nor practicable at this time to attempt the formulation of so-called "general" specifications covering all features of stand-pipe design. Various details, which do not bear directly upon the matters considered in this article, must be fixed in accordance with the local requirements. The more important of these items are: Agreement, site, foundation (including excavation, concrete, etc.), casing, anchorage, inlet pipe and valves, manhole, sizes and thicknesses of plates, kind and details of riveting, setting tank bottom, ladder or stairway, brackets, balcony, roof, and painting. The specifications given below relate solely to the structural metal and workmanship in the tank proper of the stand-pipe:

(1) Material.—The metal composing the stand-pipe shall be soft, open-hearth steel, containing not more than 0.06% phosphorus, and having an ultimate tensile strength of not less than 54,000 nor more than 62,000 lbs. per sq. in., an elastic limit not less than one-half the ultimate strength, an elongation of not less that 26% in 8 ins., and a reduction of area of not less than 50% at fracture, which shall be silky in character. Before or after being heated to a cherry red and quenched in water at 80° F., the steel shall admit of bending while cold, flat upon itself, without sign of fracture on the outside of the bent portion.

(2) Test Pieces.—All test samples shall be cut from finished material. Tensile test pieces to be at least 16 ins. long, and to have for a length of 8 ins. a uniform, planed-edged sectional area of at least ½ sq. in., the width in no case to be less than the thickness

of the piece. Bending test pieces to be 12 ins. long, and to have a width of not less than four times the thickness, with edges filed smooth.

(3) Number of Tests.—For the purpose of identification, the number of the melt or heat of steel shall be stamped on each plate produced therefrom. At least one full series of tests, both chemical and physical, as above specified, shall be made of each melt, and such additional tests may be made as, in the judgment of the inspector, seem essential for corroborative purposes under varying conditions or methods of treatment of the metal.

(4) Finish of Material.—All plates must be free from laminations and surface defects, and shall be rolled truly to the specified thicknesses.

(5) Facilities for Testing.—Complete facilities for the tests and inspections shall be provided by the contractor, as required.

(6) Inspector.—Material will be inspected at the mill by (name of a trustworthy testing concern equipped to make both chemical and physical tests) or such other party as may be approved by the engineer.

(7) Additional Test Pieces.—If required by the engineer, the contractor will provide four certified samples of each thickness of plate used in the work, these samples to be 2 ins. wide and 16 ins. long.

(8) Workmanship.—All workmanship must be first-class in every particular.

(9) Working Steel.—The plates and angles must be shaped to the proper curvature by cold rolling. No heating and hammering shall be allowed for straightening or curving, or for other purposes.*

(10) Punching.—The work shall be carefully and accurately laid out in the shop, and the rivet holes punched with a center punch, sharp and in perfect order, from the surface to be in contact. The diameter of the punch shall not exceed that of the rivet by more than 1-16 in., and the diameter of the die shall in no case exceed that of the punch by more than 1-16 in. Rivet holes in plates having a thickness of ¾ in. and over shall either be drilled or, if punched, shall be reamed not less than ⅛ in. larger than the die sides of the holes, and sharp edges shall be trimmed.

(11) Beveling, etc.—All calking edges shall be planed to a proper bevel. All parts must be adjusted to a perfect fit, and properly marked before leaving the shop.

(12) Erection. — In assembling the work, the rivet holes shall match so that hot rivets may be inserted without the use of a hammer. Drifting is prohibited. Eccentric holes, if any, must be reamed, and, if required, larger-sized rivets shall be used in such holes.

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*If lap riveting is used, omit the expression "or for other purposes," and insert the following sentence: "No scarfing shall be done at a temperature below that of ignition of a hard-wood hammer handle, and no work shall be done upon the steel between such temperature and that of boiling water."

(13) Rivets and Riveting.—The best grade of soft charcoal iron rivets to be had in the market shall be used. Sufficient stock must be provided in the rivets to completely fill the holes and make a full head. The rivets shall be driven at such a heat as will admit of their being finished in good form with a button set before the rivet has cooled to a critical point. As often as may be deemed advisable for the purpose of testing the work, rivets shall be cut out at the direction of the inspector. The quality of the rivet metal and of the workmanship shall be such that the fracture of the rivets so removed at random shall show a good, tough, fibrous structure without any crystalline appearance, and there shall be no evidence of brittleness. Loose rivets must be promptly replaced, no rivet-calking being permitted.

(14) Calking.—All seams must be calked thoroughly tight with a round-nosed calking tool by workmen of acceptable skill. Great care must be taken not to injure the under plate.

(15) Rejections.—Defective material and workmanship may be rejected at any stage of the work, and must be properly replaced by the contractor as directed.

(16) Final Tests.—After completion the work shall be tested by filling the stand-pipe with water, and the leaks, if any, shall be promptly and thoroughly calked. The stand-pipe must be water-tight before acceptance.

(17) Superintendence.—All inspections shall be made under the direction of the engineer who shall have general supervision of the work.

APPENDIX IV.—CORRESPONDENCE.*

SPECIFICATIONS FOR STAND-PIPES.

Sir: Professor Pence's article in your issue of Feb. 28 on Specifications for Stand-pipes is an extremely valuable and timely contribution to the subject. There has been, no doubt, much poor practice in this branch of engineering. The custom has been, to a greater extent than in any other engineering work of like importance, to buy a stand-pipe much as a barrel of flour would be bought; the contract or agreement would be for a stand-pipe so high and so wide, the material and workmanship to be first-class in every respect. It seemed to be thought that for so simple a thing as a stand-pipe it was not necessary to employ an engineer, and perhaps engineers were, to a certain extent, responsible for this idea, as many built stand-pipes with specifications nearly as frail as the above, and there seemed to be no effort to put the subject on a scientific basis. I presume there are many stand-pipes in existence which are supposed to have, judging from the thickness of the plates and nominal tensile strength called for, a factor of safety of from 4 to 6, which, on account of a lack of uniformity in the plates, poor design in the riveting or poor work throughout the whole structure or in certain parts of it, are strained to very nearly their real ultimate strength.

It is rather unfortunate that in a structure which is such an important part of a water-works system, the cost should be so small that it is not considered necessary to have such thorough inspection as would be required in a bridge, for instance, because the cost of such inspection is so large a percentage of the whole.

I believe the best and most satisfactory way is to place the inspection of the material at the mill and shop in the hands of an inspecting firm of good repu-

* The following communications discussing the matter presented in Appendix III. are reprinted from the correspondence columns of Engineering News,

tation, with the agreement that they shall put their private stamp upon every piece as a guarantee that it has been inspected. When the material comes upon the work, the engineer in charge can look for the stamp, and if it is not there the piece can be rejected.

It would probably not be feasible to employ a special inspector during erection on account of expense, but if the above were done, the engineer could be reasonably sure of a good job, as he should be able to pass upon the mechanical work of construction.

There are some methods of construction which it is desirable to change, but it is very difficult for a single engineer to make radical changes in his specifications, as they are usually antagonized by the makers, and result in bids in which the cost is too great, even if the actual cost is not much in excess of old methods. The design and construction of stand-pipes have been largely in the hands of the makers, and some are apt to be jealous of "engineers' notions." A certain uniformity of specifications in a general way would help in overcoming this tendency to resist new and better methods.

I will suggest a few points in which I believe there is room for improvement, and which I have not ventured to introduce into specifications as yet.

One is the method of joining the plates. The present method of lapping both horizontal and vertical seams is awkward and unmechanical, and belongs more to the methods of the village blacksmith than those of precise and scientific mechanism. They should rather be made like the accompanying sketch, Fig. 32, taken from a paper read by the writer before the New England Water-Works Association in 1893. In this sketch the horizontal seams are lapped and the vertical seams made with butt straps. This is a perfectly precise method, and requires no beating down or drawing out of the plates, and, in my opinion, would really cost no more than the old way. I use it now on plates over ½ in. in thickness, but should prefer to use it on all thicknesses.

The most important element in stand-pipe construction, after that of proper material, is the riveting of the vertical joints, and of all the work that is done, this is the most discouraging and the most effective in preventing accurate design. Specifications

require that the rivet holes shall coincide, but who has ever seen them do so, unless by that term is meant that a portion of one hole shall cover a portion of another? A drift pin is not allowed to be used (a very proper precaution), but it is not so very much better to chip out the hole and lose the metal, nor yet to force the hot rivet into a position where perhaps one-half its area is lost, as far as being effective in preventing shearing, which is the main duty of rivets in vertical joints.

I believe that the rivet holes should be punched smaller than the rivets; a ¾-in. hole should be punched ½ in.. and other sizes in proportion, and when the

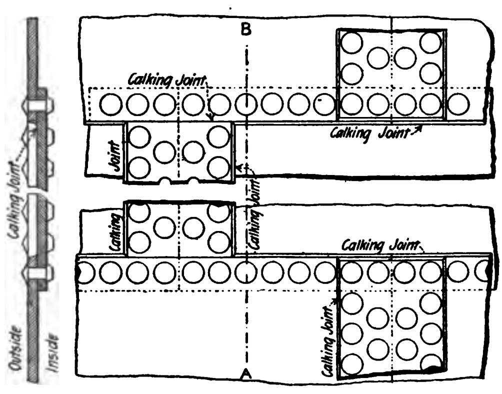


FIG. 32. METHOD OF JOINING PLATES IN STANDPIPES.

plates are in position the holes should be reamed to the proper size, both holes together. This would make a beautiful job. The hole could be made just right for the rivet, and the joint would approximate the design in strength. Now, this would not increase the expense unduly if the shops were fitted up and accustomed to do this. The reaming could easily be done by power with the proper equipment, but it would require nerve to write the first specifications in this way.

The rivets should be driven by steam or hydraulic power. This may seem radical, but I do not think so. I see no real reason why it could not be done with the suitable appliances. If field riveting can be done by power in any structure, a stand-pipe is the best form, as there are continuous rows of rivets of about the same dimensions, and the only especial form of appliance would be the yoke of the riveter, which would need to straddle a 5-ft. plate. I do not believe this is impracticable. I think it must hurt the feelings of any engineer to see two men with heavy sledges pounding away at a cool rivet, endeavoring pliance would be the yoke of the riveter, which to form a head on it. The usual result is a very thin, flat head, as the rivets are used as short as possible in order not to cause too much trouble if they happen to get cold before they are finished

I fear that my letter is already too long, but I wish to say a word about painting. The plates should be cleaned of scale and covered with raw linseed oil before being exposed to the chance of rusting. They should not begin to rust. Before being sent to the site from the shop, they should have one coat of the paint which is intended to be used, all over them; the paint for the inside of the plates on that side, and perhaps the same on the outside, but no white lead or chemical paint should be put on the inside of plates. Pure asphalt paint or varnish cut with turpentine is good.

As to the quality of material, it is true economy to require the best, whether of iron or steel. As shown by Professor Pence's tables of present market prices, the difference in cost of tank steel and flange steel is only one-fourth of 1 ct. per lb., the latter only costing about 1½ cts. per lb., while the finished stand-pipe costs approximately 4 to 5 cts. per lb.

I believe the specifications of Professor Pence for material and workmanship are quite complete and suitable. I have been using similar ones for the past year, although not quite as complete, especially for the rivets and riveting, which are particularly good.

Yours truly, Freeman C. Coffin.

Boston, Mass., March 5, 1895.

Sir: I have read Professor Pence's specifications for stand-pipes in your issue of Feb. 28, and his remarks

on the same, with a great deal of interest, and trust that they will be fully discussed as you suggest.

The only provision in these specifications for planing the sheared edges of plates is that "all calking edges must be planed to a bevel," and they do not require punched holes to be reamed in plates of under ¾ in. in thickness. This practice has the support of many engineers and manufacturers, but have we any thorough and extended series of tests to justify it? Would it not be much better to admit that all steel plates, no matter how soft the material may be, are injured by punching and shearing, and to thoroughly investigate the extent of this injury, than to go ahead, as we are now doing, without knowing very much about this matter?

The following is taken from my remarks in the discussion of Prof. Silas G. Comfort's paper on Bridge Specifications (Proc. Philadelphia Engrs' Club, Novem-

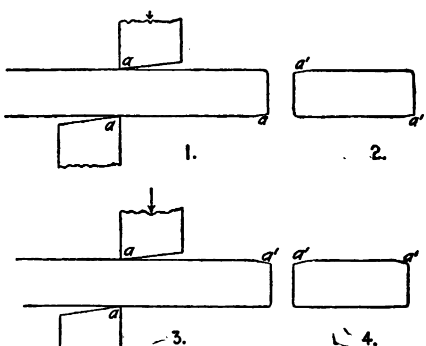


FIG. 33. EFFECT OF SHEARING SOFT STEEL.

ber, 1894), and will show the extent and character of injury caused by shearing soft steel:

Here are three pieces marked 1, 2 and 3 from a ⅝-in. steel plate (which gave 53,180 lbs. ultimate strength—46% elongation in 2 ins. and 64.6% reduction of area). They were cut side by side from the plate. This material will bend all right, as shown by Sample 3, there being no cracks on either sheared edge But Sample 1 is no good—it broke in two pieces; while in No. 2 one edge is good and the other poor.

All these bends were made over a pin in same manner by slowly applied pressure.

If you will examine these pieces carefully you will find a depression on the rolled surface extending back about one-eighth of an inch from the sheared edge (the mark is the same as the mark of die in punching, only deeper). The metal here was in contact with the shear knife, a, Fig. 33 (1), and has been compressed and hardened, and will not stand the bending test when on the outside of curve—that is, after being compressed it will not stretch. The rolled surface on the other side of plate at corresponding sheared edges is rounded, and will stand much better when on the outside curve. It is not the fine wire edge that causes the trouble, as you can remove it, and yet the plates will not stand bending.

Sample 2 was sheared in the usual way, as shown in Fig. 33 (1 and 2), that is, after shearing one edge the plate was inserted a little further and a second cut taken, giving one compressed edge, a^1, and one rounded edge on each side of the plate; therefore you cannot get a good bend whichever side of the plate you have up.

In the other samples the plate was turned over after making the first cut, and both of the compressed edges brought on same side of the plate, Fig. 34 (3 and 4). (This can also be done by turning the plate around, but it is hard to hold in shearing.) In Sample 3 both of the compressed edges were on the inside of curve, and the bend is good, while in Sample 1 they were both on the outside, and it is no good.

This, no doubt, is old to many of the members, but may be of interest to some of the younger members.

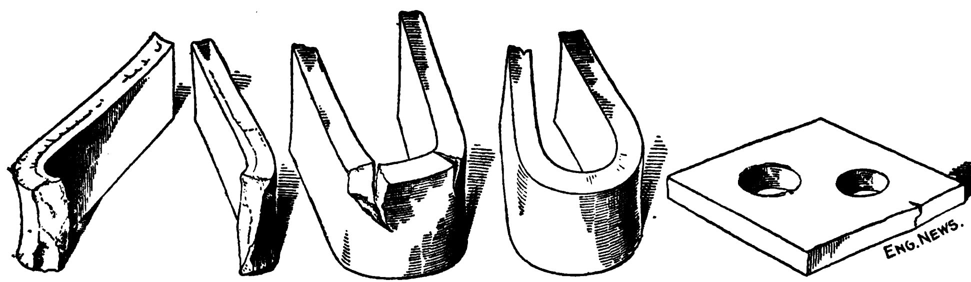
The samples of drifting tests had two ¾-in. holes punched in them, and one hole in each case has been enlarged to 1½ times its diameter, while in attempting to enlarge the other hole the plate in each case has broken at the edge. The poor results or failures were caused by using a drift with very slight taper—the metal would not stretch at sheared edge where it had been compressed and hardened. In the other cases a drift of much greater taper was used; it thickened the metal up around the holes; then a drift of less taper was used and the holes enlarged.

The sketches, Fig. 34, of these bent pieces, Samples 1, 2 and 3, and of the piece subjected to drifting, Sample 4, show fairly well the results of the tests.

Article 10 of Professor Pence's specifications reads:

Punching.—The work shall be carefully and accurately laid out in the shop, and the rivet holes punched with a center punch, sharp and in perfect order, from the surfaces to be in contact, etc.

This, as was stated, brings the bevel of the holes away from the surface in contact; that is, on the plates in outside courses the indentation made by the



1. 2. 3. 4.

FIG. 34. SAMPLES 1. 2. 3 AND 4.

bottom die in punching (corresponding to the indentation "a," Fig. 33, in shearing) is on the outside of the curve, and in the very worst conditi n to withstand the action of the bending rolls.

In order to see how this would work out in practice, the following tests were made for me by Mr. S. M. Vauclain, Superintendent of the Baldwin Locomotive Works:

Two pieces of open-hearth steel boiler plates, ⅝ in. thick, were sheared to 6 x 24 ins., the plates being sheared in the usual manner, giving in each one longitudinal edge rounded, and the other with depression, "a," Fig. 33. Two lines of 25-32-in. holes were punched with 2-in. pitch, centers 1⅛ ins. from edges of plates. One-half of these holes were punched from one side of the plates, the plate turned over and the balance of holes punched. This gave in each plate the conditions of punching of both outside and inside plates in a stand-pipe. As these plates were to be bent, they were marked near the holes "punched from inside," or "punched from outside," corresponding with proposed manner of bending.

The edges of one of these plates, Sample 6, Fig. 35. were planed and all the holes reamed; those punched from the inside were reamed 1-16, and those from outside ⅛ in. Both pieces were then bent in bending rolls to a curve, 16 ins. in diameter; neither showed any cracks at holes or edges of plates. They were then closed down under a hydraulic press to a circle of 8½ ins. diameter, as shown in Fig. 35. Sample 6, with reamed holes and planed edges, did not show any cracks at either edges or holes, but Sample 5, with sheared edges and punched holes, cracked at all holes punched from the inside, and at several places along the sheared edge "a," Fig. 33, but none of the holes punched from the outside cracked.

Two pieces of Bessemer steel plate, ½ in. thick, were sheared to 6 x 36 ins., and punched the same as before. They are shown by the sketch, Fig. 36. Sample 7 has sheared edges and punched holes, while Sample 8 has planed edges and reamed holes. These pieces were bent in bending rolls, but when Sample 7 reached a curve of 20 ins. diameter, the plate had cracked in four places from the sheared edge "a," Fig. 33, to the punched holes. In three cases the holes were punched from the inside, and in the

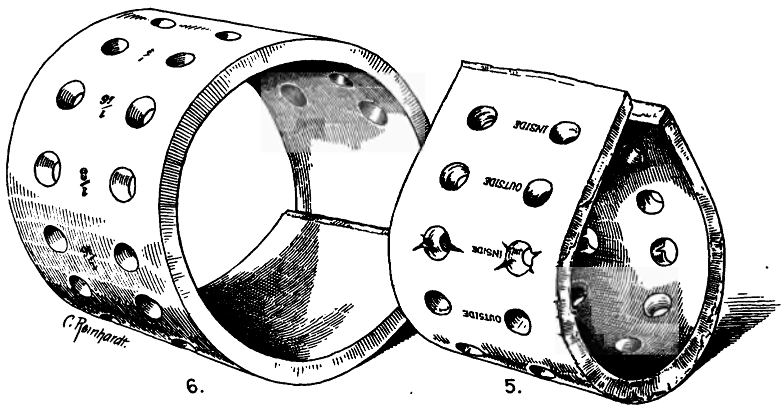


FIG. 35. SAMPLES 5 AND 6, ⅝-IN. OPEN-HEARTH STEEL BOILER PLATE.

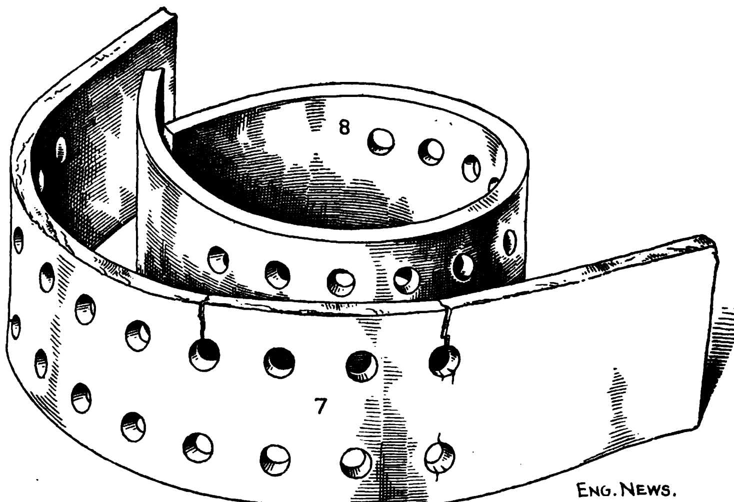


FIG. 30. SAMPLES 7 AND 8, ½-IN. BESSEMER STEEL PLATE.

fourth from the outside. In the last case the crack no doubt started from the edge of the plate, as none of the other holes punched from the outside cracked at all.

Sample 8 was bent to a curve of 20 ins. diameter on bending rolls, and then forced down under hydraulic press to a curve of 8½ ins. diameter, without showing any cracks in the metal at the reamed holes or planed edges.

The tension tests and analyses of this material are shown in the accompanying table:

Tension Tests and Analyses of Test Plates Nos. 5, 6 and 7.

	⅝-in. open-hearth steel plates, No. 5.	⅝-in. open-hearth steel plates, No. 6.	½-in. Bessemer steel plates, Nos. 7 and 8.
Elastic limit, lbs......	34,180	32,700	31,000
Ultimate strength, lbs.	61,200	60,900	60,880
Per cent. stretch, lbs..	28.87	29.12	21.87
Carbon	0.22	0.21	0.18
Manganese	0.39	0.47	0.46
Sulphur	0.037	0.014	0.040
Phosphorus	0.017	0.014	0.112

The Bessemer steel plate contains much more phosphorus than the open-hearth steel, but no more than some of the steel used in stand-pipes.

If we take into consideration the results of the bending test on Sample 7, and the drifting test 4, it is not a very hard matter to build up a theory of the cause of some stand-pipe failures. But this is not the question. It is, how to guard against these failures in the future. I would respectfully submit the following:

That in all stand-pipe work the sheared edges of steel plates should be planed before the holes are punched, as small cracks are often started at the sheared edge by punching (same as by drifting, Sample 4). These cracks may not be removed by subsequent planing of the edge, and would be enlarged when the plates are bent in the rolls. I know that it is a little more convenient to punch the plates first, and then set them at the planer by passing two or the punched holes over pins, and then planing off the edge. This practice is not uncommon, but a few experiments on this point will convince any shop superintendent that he can get better results by planing the plates first.

The same plan of working holds good for punching and reaming, even when the edges of plates have been planed first. This work should all be done in the following order: Plane edges, punch holes, ream holes, and then bend plate. But it is not at all uncommon, even in boiler work, to carefully plane the edges of steel plates, punch holes, bend in rolls, assemble plates, and then ream. The above experiments show how much better it would be to ream the holes before bending, even if some additional reaming had to be done after assembling. Yours truly, Wm. R. Webster.

3310 Hamilton St., Philadelphia, March 30, 1895.

SPECIFICATIONS FOR THE SCHENECTADY STAND-PIPE.

Sir: We enclose a copy of the specifications recently prepared by us for a steel stand-pipe in connection with the new water supply for the city of Schenectady, N. Y. You will notice that the specifications for material are taken bodily, with few changes, from the specifications for steel stand-pipes by Professor Pence, published in Engineering News of Feb. 28, 1895, which seemed to us so good in both matter and wording as to make any material change in either undesirable. We enclose a list of the bids received on May 9. We take this means of acknowledging our indebtedness to your paper. Yours truly,

The Stanwix Engineering Co.

Rome, N. Y., May 18, 1895.

(The stand-pipe called for was 32 × 100 ft., on foundations to be furnished by the city. The steel is to be soft open hearth, with not over 0.08% phosphorus for acid or 0.06 for basic steel. The thickness of the plates, from the bottom upwards, and the details of rivets and joints, are shown in the accompanying table.

It is interesting to note that the specifications require that the stand-pipe shall be painted with "two coats of black varnish approved by the engineer and of a quality equal to Edward Smith & Co.'s 'Black Bridge Paint.'" This "paint" we understand to be a modification of Prof. A. H. Sabin's Japan coating for water pipes and other metal, described in our issue of Feb. 7, 1895. The latter requires that the metal to which it is applied must be

baked, but this "paint," which is really a varnish, is so prepared as to make baking unnecessary.

Three formal bids for the stand-pipe were received on May 9, 1895, under the above specifications, as follows: Ranton Boiler Co., Syracuse, N. Y., $8,335, to whom the contract was awarded; Riter & Conley, Pittsburg, Pa., $9,638; Enterprise Boiler Co., Youngstown, O., $10,994. The Elmira Machine Co. bid $9,100, but did not enclose the required check, and Tippett & Wood, Phillipsburg, N. J., offered to build a wrought iron stand-pipe for $9,045. —Ed.)

Thicknesses of Plates and Details of Joints and Riveting in the New Stand-Pipe for Schenectady, N. Y.

		Rivets.				
Course.	Thickness plate, ins.	Diameter, ins.	Pitch, c. to c., ins.	Dist. between pitch lines, ins.	Kind of vertical joint.	Thickness cover plates, ins.
1..	⅞	1	3⅛	2⅝	D'b'e-riv'd butt	½
2, 3..	13-16	1	3⅛	2⅝	" "	7-16
4..	¾	1	3	2½	" "	7-16
5..	11-16	⅞	2⅞	2⅜	" "	⅜
6, 7..	⅝	⅞	2⅞	2⅜	" "	⅜
8..	9-16	⅞	2⅞	2⅜	" "	5-16
9, 10..	½	⅞	2⅞	2⅜	" "	5-16
11..	7-16	¾	2½	2	" "	¼
12..	⅜	¾	2½	2	" "	¼
13..	⅜	¾	2¼	1¾	D'ble-riv'd lap	..
14, 15..	5-16	⅝	1⅞	1⅜	" "	..
16..	¼	⅝	1⅞	1⅜	" "	..
17, 18..	3-16	½	1¾	1¼	" "	..
19, 20..	3-16	½	1½	...	S'gle-riv'd "	..

Horizontal courses are to be placed alternately inside and outside, with single-riveted lap joints, these rivets to correspond in size with those given in the table for the same thickness of plate, the pitch to be three diameters of the rivets. All butt joints shall have inside and outside covering straps. The distance from the edge of any piece to the edge of the rivet holes shall not be less than 1½ diameters of rivet.

THE ST. BERNARD, O., STAND-PIPE.

(The following abstract of an article by Mr. Geo. Hornung, M. Am. Soc. C. E., which appeared in Engineering News of May 23, 1895, is presented at this place because of its relation to the matter contained in Appendix III., but mainly on account of the light which it throws upon recent developments in stand-pipe erection. In the valuable communication from Mr. Freeman C. Coffin, M. Am. Soc. C. E., reprinted in this Appendix, the suggestion is made (pp. 178-9) that power riveting should be used in erecting stand-pipes. It is certainly a significant and hopeful fact that this timely suggestion was anticipated by several months by the progressive contractors for the St. Bernard stand-pipe. The methods and appliances there used are described below.)

The stand-pipe is 20 ft. in diameter, and its height 115 ft. The plates were of "homogeneous steel," to have the properties shown in the last column of the following table (which also shows the results of tests of the material):

	By test.	Specified.
Minimum tensile strength, lbs.......	55,180	55,000
Maximum " " "	64,260	63,000
Average " " "	59,455	......
" elastic limit, lbs............	36,594	......
" elongation, per cent........	31	25
" reduction of area, per cent..	57	50
" phosphorus, " "	0.02	0.06
Appearance of fracture..............	Silky angular.	

The inspections were made at the mills by "a person of recognized ability" who certified to their correctness. The metal displayed marked ductility in the process of drilling and planing. The thicknesses of the plates were as follows:

No of course.	Thickness, ins.	No of course.	Thickness, ins.
1, 2	13-16	12	½
3	¾	13, 14	7-16
4-8	11-16	15	⅜
9	⅝	16, 17	5-16
10, 11	9-16	18-23	¼

FIG. 37. STAND-PIPE UNDER CONSTRUCTION FROM INSIDE SCAFFOLDING, ST. BERNARD, O.

The rivet holes in plates thicker than 7-16 in. were required to be drilled, but it was allowed that the holes in plates 7-16 in. and less in thickness should be punched and reamed, provided no damage resulted from the punching. The horizontal seams are riveted throughout. The vertical seams are triple in the six lower, and double in the remaining courses. The spacing of rivets was not specified numerically, but it was provided that the riveting should be designed so as to make the shearing strength of the rivets equal to the tensile strength of the reduced plate section. Drifting was prohibited.

A noteworthy innovation in the erection of this stand-pipe was the use of a pneumatic riveting machine, which was employed throughout in riveting the shell together. The machine and the operator's platform are shown in the view, Fig. 37, as they are suspended and swung into position for work.

Another interesting feature of the work of erection was the derrick or staging. This consisted of an inside framework, thoroughly braced, with a platform on top, supporting a pivoted boom. This boom rested on rollers running on a track about the edge of the platform. In operating the boom one arm carried the traveling carriage, with which the load was hoisted and held in place, and from the other arm was suspended a corresponding counterweight attached to a line, as shown in Fig. 37. The hoisting line, after it left the traveling carriage, passed down the center of the scaffold into the masonry archway or valve chamber under the tower, and thence to the drum of the hosting engine. This stage and boom proved to be highly satisfactory, and when damaged during a windstorm early in 1895, it was quickly and easily repaired. L. Schrieber & Sons Co., of Cincinnati, O., the contractors for the stand-pipe, claim that the use of this type of derrick for stand-pipe erection is original with them. The cost of the superstructure of the St. Bernard stand-pipe was $6,189. It was completed and filled with water the first time on March 27, 1895.

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